Comparison of atlas data to determine the conservation status of bird species in New South Wales, with an emphasis on woodland-dependent species

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ABSTRACT

An overview of changes to the distribution and numbers of New South Wales birds was considered in relation to the IBRA bioregions, using data from Birds Australia's first and second national bird atlases (*Atlas 1*, 1977 – 1981 and *Atlas 2*, 1998 – 2001). Reporting rates, adjusted for survey effort, were compared for 347 bird species. Of these, 184 species (53%) showed no change between the two atlases, 83 (24%) were recorded more frequently during *Atlas 2*, and 80 (23%) were recorded less frequently during *Atlas 2*. This represents a greater proportion of declining bird species in NSW compared with the whole of Australia – one previous study found that 15% of 422 species had declined nationally. Of 139 woodland species tested, 33 (24%) were recorded less frequently during *Atlas 2*, a similar proportion to the broader pattern for all NSW bird species (23%). Woodland birds represented 41% of the declining bird species in NSW, 43% of the increasing species and 38% of species showing no change between the two atlases. Based on IUCN criteria, the current study indicates that 56 bird species may qualify as threatened in NSW. A brief case study is presented for one such species, the Gang-gang Cockatoo, which has subsequently been listed as threatened.

Our study also identifies possible drivers of regional patterns by modelling changes in reporting rate for individual woodland bird species against a selection of bioregional features from the National Land and Water Resources Audit, *Landscape Health in Australia* database. Bioregions with greater rainfall had increased reporting rates and greater woodland bird diversity in *Atlas 2* compared with *Atlas 1*. Reporting rates for individual woodland bird species responded both positively and negatively to the % native vegetation cover and the % area grazed by livestock within bioregions.

Key words: Bird atlas, woodland birds, bioregion, landscape modelling, NLWRA, IUCN criteria

Introduction

There is evidence that a number of bird species have declined in New South Wales over the last 20 years (Garnett and Crowley 2000) and concern that without action being taken, a large proportion of the avifauna in Australia's agricultural and pastoral zones will be lost (Recher 1999). The combined effects of clearing for agriculture and grazing by livestock in the temperate woodlands means woodland birds are well represented among the declining species (Barrett *et al.* 1994; Ford *et al.* 2001; Watson *et al.* 2003). Six woodland bird species were listed as Vulnerable under the NSW *Threatened Species Conservation Act 1995* in 2001, these numbering among 20 species identified by Reid (1999) as likely to be threatened in the near future. It should be noted that, at the same time, many woodland bird species have become more common in agricultural landscapes, being favoured by moderate levels of livestock grazing, as well as the creation of open, edge habitat as a consequence of woodland fragmentation.

Accurate measures of change over time are essential to the assignment of conservation status to wildlife, allowing declining species to be identified before they reach critically low population levels (Caughley and Gunn 1996, Fewster *et al.* 2002). It is also important to provide monitoring data at relevant jurisdictional scales, so that bioregional analyses can be aligned with planning processes for land management. The completion of the New Atlas of Australian Birds (*Atlas 2*, 1998 – 2001) marked the establishment of an Australia-wide bird monitoring program, where fixed effort, community-based surveys continue to provide accurate, on-going monitoring data for the majority of Australia's bird species (Barrett *et al.* 2003). Furthermore, the on-going atlas is based on surveys at specific points that can be amalgamated, allowing interpretation at a range of geographical scales. Already, these data are proving to be a powerful tool for assessing the state of Australia's birds (Olsen *et al.* 2003, Olsen and Weston 2004). The NSW Atlasser's regional bird monitoring program is another example of the use of atlas data to identify long-term relationships between birds and land use patterns (Cooper and McAllan 1995, for an overview of atlassing in Australia see Barrett *et al.* 2003). The new atlas (*Atlas 2*) also provided an opportunity for a broad-brush assessment of changes to birds over the last 20 years, by comparing the reporting rates for individual species with those from the first Atlas of Australian Birds (*Atlas 1*, 1977 – 1981, Blakers *et al.* 1984). Such an analysis was carried out by Birds Australia for 422 bird species, of which 64 (15%) were recorded less frequently during *Atlas 2* compared with *Atlas 1*, including many woodland species that showed declines of up to 50% (Barrett *et al.* 2003). In a preliminary analysis of national and bioregional trends using atlas data, Garnett *et al.* (2002) highlighted a decline in reporting rates for woodland bird species on the western slopes of the Great Dividing Range, particularly of ground-foraging, insectivorous birds. They related these trends to the extent of native vegetation retention, landscape stress and changes in rainfall across IBRA bioregions (Interim Biogeographic Regionalisation for Australia, Thackway and Creswell 1995).

With a view to prioritizing species and actions within the proposed recovery planning framework for woodland birds, the Department of Environment and Climate Change NSW (formerly DEC, and prior to that, the NSW National Parks and Wildlife Service) approached Birds Australia to undertake a review of changes to the distribution and numbers of bird species in New South Wales over the 20 years between *Atlas 1* and *Atlas 2*. This paper presents the results of that review, considered in relation to the New South Wales IBRA bioregions. It builds on a preliminary report produced for the DEC, assessing changes in NSW bird species between the two bird atlases (Barrett and Silcocks 2002), as well as the analysis for the National Land and Water Resources Audit, carried out by Garnett *et al.* (2002).

Our aims were to determine whether 1) there have been changes in the reporting rate and hence population status, of woodland birds in New South Wales over the last 20 years, 2) whether these trends are uniform across IBRA bioregions, and 3) to assess changes to reporting rates within each bioregion, against a selection of bioregional features from the National Land and Water Resources Audit *Landscape Health in Australia* database (NLWRA 2001). It should be noted that the focus of our study was on spatial relationships between individual woodland bird species and selected, static attributes of IBRA bioregions, such as the % native vegetation cover, for which no trend data are included. The patterns identified are intended as hypothesis generators for possible causes of broad scale changes in reporting rates for individual bird species, and presented here as relationships worthy of further investigation. The results can be used by DECC and the newly created NSW Catchment Management Authorities (CMAs) to assist with setting priorities for recovery actions for woodland birds across New South Wales. The analysis of change between *Atlas 1* and *Atlas 2* for 347 individual bird species is presented in Appendix 1. Generalised linear models, identifying relationships between changes to reporting rates for individual woodland bird species and selected environmental variables from the LWRA database, are presented in Tables 4 and 5. An additional assessment of changes to reporting rates was carried out for each of the 17 NSW IBRA bioregions (Electronic Appendix), with maps displayed for a selection of 18 species that showed significant differences in reporting rate between the different IBRA bioregions (Appendix 3).

Methods

Bird surveys

The reporting rate for individual bird species was compared between the first Atlas of Australian Birds (*Atlas 1*) which continued for five years between 1 January 1977 and 31 December 1981, and the New Atlas of Australian Birds (*Atlas 2*), which ran for three years and five months, from 1 August 1998 to 30 December 2001. *Atlas 2* surveys continued beyond this main *Atlas 2* period and some that were completed as late as February 2002 were included in the analysis.

During *Atlas 1*, volunteer observers searched a 10-minute grid (approximately 15 km × 17 km) recording all bird species seen or heard, producing a bird list for each grid. These *Atlas 1* surveys were compared with two types of survey from *Atlas 2*; Area Searches within 500 m and Area Searches within 5 km, both focused around a central point and lasting at least 20 minutes (no longer than a day). Both the *Atlas 1* and *Atlas 2* surveys were grouped by 1° grids and a reporting rate (number of sightings divided by the total number of surveys) was calculated for each grid. Surveys were allocated to bioregions on the basis of the dominant bioregion within each 1° grid.

All surveys were extensively vetted using expert committees, familiar with their local birds. A total of 139 species are referred to as woodland birds, being primarily associated with patches of woodland or open forest in the temperate or semi-arid regions of NSW. In addition to habitat preference, species range and ecology were also considered when identifying woodland birds, as per Frith (1976) and Ford *et al.* (1986). For scientific names see Appendix 1, Tables 1-6 (woodland species are shaded). For a full description of the data collection, as well as the vetting and processing methods used in *Atlas 1*, see Blakers *et al.* (1984) and for *Atlas 2*, see Barrett *et al.* (2003).

Changed survey methods

The comparison of atlases was to some extent confounded by the change in survey methods from 10-minute grid searches in *Atlas 1*, to the 500 m and 5 km point-based searches in *Atlas 2*. In order to quantify the effect of survey method on the comparison of atlases, observers who took part in *Atlas 1* were encouraged to repeat some surveys using the same method they had used during that first atlas. As a result, 1,771 × 10-minute grid surveys (*Atlas 1* method) were completed during *Atlas 2* (1998-2001), mostly in NSW. Below is a summary of the results from the comparison of *Atlas 1* and *Atlas 2* survey methods for the whole of Australia. For a fuller description of the analysis of bias caused by using different survey methods, see Garnett *et al.* (2002) or Barrett *et al.* (2002; 2003).

Of 202 bird species compared, four were more likely to be recorded using *Atlas 2* methods than *Atlas 1* survey methods (Appendix 1, identified by ▲ in Tables 1-6). So even if there was no actual difference in reporting rate between the two atlases for these four species, the changed survey method was likely to have resulted in these species being recorded more frequently in *Atlas 2*. By contrast, 47 species (23%) were less likely to be recorded using *Atlas 2* methods (Appendix 1, identified by ▼), and 151 species (75%) showed no significant change between the *Atlas 1* and *Atlas 2* survey methods. There was evidence of regional variation in the way the reporting rate changed between *Atlas 1* and *Atlas 2* survey methods for 18 bird species (9%). That is to say, the *survey method effect* varied depending on the IBRA bioregion considered. The remaining 184 species showed no regional variation.

In conclusion, the change from grid-based surveys in *Atlas 1* to point-based surveys in *Atlas 2* was likely to affect about a quarter of the species tested, and in almost all cases, the bias was towards those species being under-reported in *Atlas 2*. These species tended to be larger, more conspicuous and regularly seen along roadsides, and is partly explained by surveys being carried out from moving vehicles during the first atlas. The tightening up of survey methods in *Atlas 2* will suggest a decline in such species where no decline has in fact occurred, the difference actually being due to the changed method. In addition to the visibility of the birds themselves, Garnett *et al.* (2002) identify the size of the survey area as a source of bias between the two atlases. A larger area was usually surveyed during *Atlas 1* surveys, resulting in more species being recorded in each survey and higher reporting rates. Site selectivity by observers is another potential source of bias, with birds from open agricultural land likely to be underestimated during *Atlas 1*, while birds occurring in habitats of greater interest to observers, or birds of greater interest, were likely to be over-estimated during *Atlas 2*. For example, regionally rare species with a high profile, such as the Square-tailed Kite, Gilbert's Whistler, Regent Honeyeater, Turquoise, Swift and Superb Parrot may have been recorded more frequently in *Atlas 2* because people were more aware of their threatened status and so, more likely to carry out surveys where existing populations were known to occur. Another artifact of community-based surveys is that bird identification skills have improved in recent years due to the availability of new field guides, bird call tapes and improved optical equipment. This may have resulted in taxonomically indistinct species such as some of the thornbills and smaller lorikeets being more easily identified during *Atlas 2*.

Changed climatic conditions

In Australia rainfall drives many natural processes and is likely to account for some of the differences in bird species reporting rate identified between the two atlases (Nix 1976; Woinarski and Braithwaite 1990). Changes in rainfall between *Atlas 1* and *Atlas 2* were assessed for each of Australia's biogeographic regions (Figure 1). The rainfall index was derived for the two atlas periods by Garnett *et al.* (2002) from long-term averages reported by the Bureau of Meteorology (http://www.longpaddock.qld.gov.au/RainfallAndPastureGrowth/NSW/index.html). Because of a likely lag time between rainfall and changes in bird numbers, averages were arbitrarily lagged by six months. Annual averages were calculated for each subregion within the IBRA bioregions, for each year bird surveys were carried out, and then were given a rainfall score relative to the long-term average (−3 = <10 rainfall percentile, −2 = 10-20 rainfall percentile, −1 = 20-30 rainfall percentile, 0 = 30-70 rainfall percentile, 1 = 70-80 rainfall percentile, 2 = 80-90 rainfall percentile, 3 = >90 rainfall percentile). A rainfall score for each bioregion was then determined by averaging the scores for each subregion on the basis of area, and a rainfall index (RI) was calculated as the difference between scores (*Atlas 2* – *Atlas 1*). This was then coded as, *Drier* (RI < −0.5, no bioregions were drier during *Atlas 2*), *No Change* (–0.5 < RI > 0.5), *Wetter* (0.5 < RI > 1.0) or *Much Wetter* (RI > 1.0, see Garnett *et al.* 2002 for details). The resulting change map demonstrates that much of northern NSW, as well as the western slopes of NSW, experienced increased rainfall in *Atlas 2* compared with *Atlas 1* (Figure 1, see also Table 1).

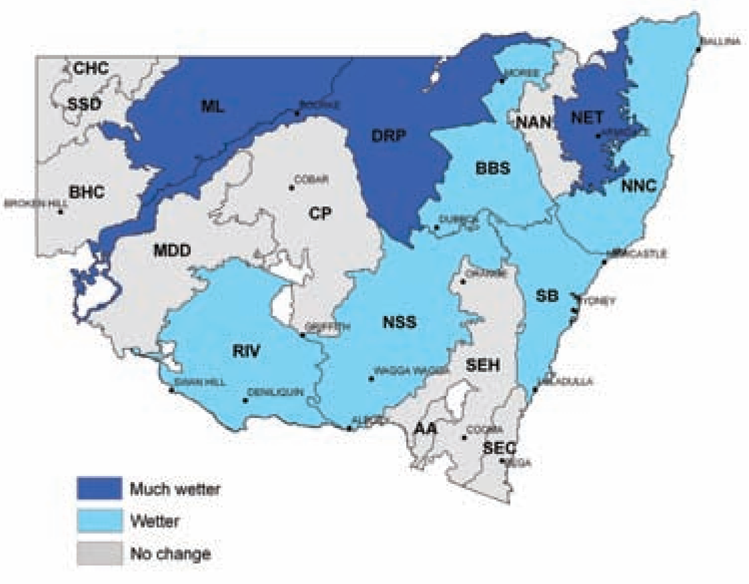

Figure 1. Rainfall in *Atlas 2* relative to *Atlas 1*. Bioregions classified as *No Change, Wetter* or *Much Wetter* in *Atlas 2* compared with *Atlas 1* (no bioregions were drier). After Garnett *et al.* 2002. For bioregion codes see Table 1.

Table 1. Estimates of landscape stress, % native vegetation and % area impacted by grazing stock, for each IBRA bioregion, from National Land and Water Resources Audit *Landscape health in Australia* database (2001). Values for subregions were averaged for each IBRA bioregion. 1 = low stressed landscape, 6 = highly stressed landscape. Changes in average rainfall in *Atlas 2* compared with *Atlas 1* are derived from Garnett *et al.* (2002, Figure 1).

IBRA bioregion	Code	% Native vegetation	Landscape stress	% Grazed area	Rainfall in Atlas 2 compared with Atlas 1
Channel Country	CHC	100	3	76	No change
Mulga Lands	ML	97	4	90	Much Wetter
Broken Hill Complex	BHC	99	4	82	No change
Australian Alps	AA	96	1	7	No change
Riverina	RIV	60	2	88	Wetter
Cobar Peneplain	CP	70	3	96	No change
Simpson-Strzelecki Dunefields	SSD	100	3	75	No change
NSW Southwestern Slopes	NSS	16	5	91	Wetter
South Brigalow	BBS	36	3	95	Wetter
Murray-Darling Depression	MDD	94	4	74	No change
Darling Riverine Plains	DRP	77	3	97	Much Wetter
South Eastern Highlands	SEH	42	6	73	No change
Nandewar	NAN	40	3	85	No change
South East Corner	SEC	84	2	71	No change
New England Tableland	NET	47	3	83	Much Wetter
NSW North Coast	NNC	61	3	78	Wetter
Sydney Basin	SB	67	4	37	Wetter

Landscape stress, % native vegetation and % grazed area

Measures of landscape stress for each IBRA bioregion were available from the National Land and Water Resources Audit *Landscape Health in Australia* database (NLWRA 2001, http://www.deh.gov.au/metadataexplorer). These are based on a rapid assessment of the relative condition of Australia's bioregions which described highly stressed landscapes as typically having between 30% and 50% of the native vegetation remaining in a highly fragmented state, and at least 70% of the area with a history of heavy grazing (Morgan 2001). The relative landscape health and biodiversity status for each subregion of Australia's bioregions were also assessed by Morgan, using indicators such as land use, extent and continuity of native vegetation, soil and hydrology features, existence of threatened ecosystems and threatened species, as well as the density of weeds and feral pests. Morgan combined these indicators to produce a continental landscape stress score for each subregion (a single assessment of landscape stress across the intensive and extensive land use zones). In most cases there were more than four sub-regions of varying size for a given IBRA bioregion and for the current analysis, scores were averaged across each IBRA bioregion (Figure 2, Table 1). In the NLWRA database a score of one represents a relatively high stressed landscape, usually associated with Australia's intensive land use zone, whereas a score of five represents a relatively low stressed landscape. For the purposes of this study, the scores were reversed to be more intuitive (1 = low stress, 5 = high stress). Estimates of the current % native vegetation (including non-woody vegetation, Figure 3) were also available for each IBRA bioregion, as were estimates of % area with least impact from grazing. By subtracting from 100, the latter scores were converted to a broad estimate of % area impacted by grazing stock. Note that these are static environmental attributes describing the current situation, saying nothing about how the IBRA bioregions have changed over the last 20 years.

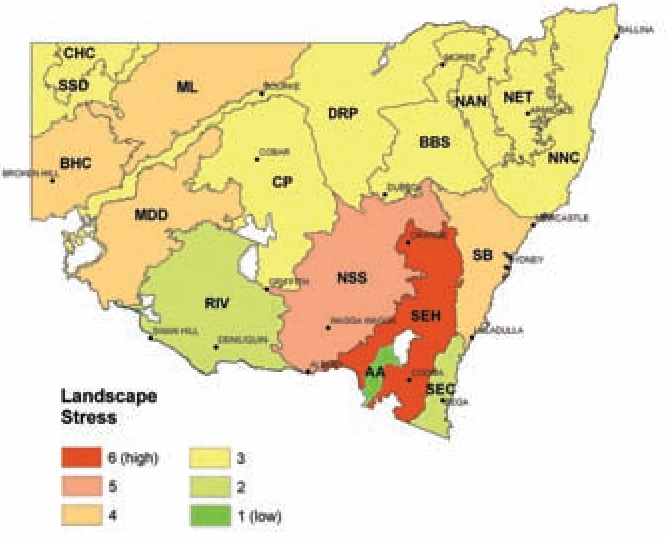

Figure 2. Landscape stress for NSW IBRA bioregions, from the National Land and Water Resources Audit *Landscape health in Australia* database (adapted from NLWRA 2001). Landscape stress was assessed using indicators such as land use, extent and continuity of native vegetation, soil and hydrology, impact of grazing stock, existence of threatened ecosystems and threatened species, density of weeds and feral pests. For bioregion codes see Table 1.

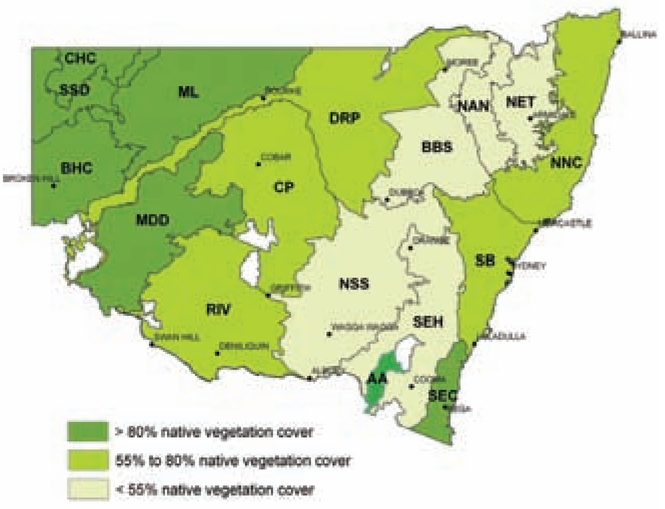

Figure 3. % Native vegetation for NSW IBRA bioregions (includes non-woody plants), from the National Land and Water Resources Audit *Landscape health in Australia* database (NLWRA 2001). For bioregion codes see Table 1.

Analysis

It needs to be clearly stated that the analysis of change in bird species' reporting rates between *Atlas 1* and *Atlas 2* was based on a comparison of two points in time, roughly 20 years apart. Change or no change in the status of each species was inferred from a comparison of the reporting rate between the two atlases using general linear mixed models, within the GENSTAT 5.4.1 statistical framework (GENSTAT, 1993). A random effect was fitted for 1°grid within each bioregion (Appendix 2). Reporting rate (RR) was the measure chosen for the analysis and defined as the number of surveys in which a bird species was recorded as present, expressed as a proportion of the total number of surveys in a particular 1° grid.

Declining or increasing species were defined as those showing a significant reduction or increase in the reporting rate in *Atlas 2* compared with *Atlas 1* ($p<0.05$, Appendix 1). Reporting rate data were log transformed to improve normality of distribution. For some bird species, the mean reporting rate was partly dependent on survey effort, an unusual result related to the spatial distribution of the species and the spatial distribution and behaviour of observers. As a consequence, the models were statistically adjusted for possible differences in survey effort between the atlases for each grid (Adjusted RR, Appendix 2). Apart from excluding 1° grids with fewer than five surveys (in either atlas) and bird species recorded fewer than 30 times (both atlases combined), all IBRA bioregions were given equal weight in the modelling analysis. In their analysis of national trends, Garnett *et al.* (2002) found that in most cases, core bioregional reporting rates (in which peripheral bioregions were removed) were similar to national reporting rates (in which all biroegions were included), with some differences occurring in the more mobile species, notably the inland parrots. For a fuller description of the modelling procedure used to identify changes to bird species reporting rates, and whether these were uniform across bioregions, see Appendix 2.

Drivers of regional variation

Changes in reporting rate were also calculated for each bird species in each of the 17 IBRA bioregions within NSW (Electronic Appendix, Tables 1 to 17). The % Change figure used was defined as [(*Atlas 2* RR – *Atlas 1* RR)/*Atlas 1* RR] × 100. Note that dividing the difference in reporting rate (*Atlas 2* RR – *Atlas 1* RR) by the original *Atlas 1* reporting rate, puts greater emphasis on the less common species. These % Change scores were then converted to a positive scale by adding the lowest score to all scores. An iterative, interactive model building process was used (Henderson and Velleman 1981) to identify relationships between environmental variables associated with each bioregion and changes in reporting rate for individual woodland bird species that had previously been identified as declining, increasing or or showing no significant change in reporting rate across NSW (Appendix 1). The four environmental variables from the NLWRA database were: % native vegetation; landscape stress; % grazed area and rainfall (Table 1). Only bird species recorded in at least 20 surveys were included in the modelling analysis (Atlasses combined), which excluded 10% of species with the lowest reporting rates. Dispersion parameters were estimated for each model, residual variations were checked and data were log or square root transformed as necessary. Parameter estimates and variances were checked for each explanatory variable. Those that were more highly significant and explained a greater portion of the variance, were placed in the model first, followed by the next most significant variable, until the addition of further variables had no significant effect on the model (Tabachnick and Fidel 1989). As described by James and McCulloch (1990), explanatory variables were selected in such as way that the models were simple and ecologically meaningful. Significant interactions were identified. To simplify models and, where differences between levels within explanatory variables were non-significant ($p<0.05$), the levels were combined into fewer categories (for example, combining landscapes stress levels).

Distribution maps are provided for 18 bird species (Appendix 3) that showed significant regional variation in the change in reporting rate between the atlases ($p<0.05$, Appendix 1, Tables 1 to 3). An arbitrary 20% threshold was used to identify bioregions where reporting rates for each species had increased or decreased, a threshold that is comparable to recognized alert limits for declining birds. For example, the British Trust for Ornithology, has adopted a 25% change in reporting rate over 25 years to to indicate 'significant long-term decline' (http://www.bto.org/birdtrends2005/key_findings.htm, see also Fewster *et al.* 2000). Bird species with a < 20% change in reporting rate were identified as showing no change. Bioregions with fewer than 40 surveys for both atlases (combined) were excluded, as were bird species with a reporting rate that was less than 0.03 in both atlases (see Electronic Appendix for reporting rates for each IBRA bioregion). This threshold of 20% change in reporting rate was also applied when calculating the proportion of bird species increasing, decreasing or showing no change in reporting rate, in the different bioregions (Table 2).

Table 2. Proportion of bird species that showed a decline or increase in reporting rate between *Atlas 1* (1977-1981) and *Atlas 2* (1998-2001), within each NSW IBRA bioregion. For example, 36% (52 species) of the 144 species recorded in the Channel Country (CHC) were found to have declined within this bioregion. Similarly, 40% (21 species) of the 53 woodland species recorded in the Channel Country (CHC) were found to have declined within this bioregion. Declining species showed at least a 20% decrease in reporting rate, increasing species showed at least a 20% increase in reporting rate within the bioregion (see main text for definition of % Change in reporting rate).

		All Species				Woodland Species			
IBRA bioregion	Code	% Species with >20% decrease in RR	% Species with >20% increase in RR	% Species showing no change	No. Spp	% Species with >20% decrease in RR	% Species with >20% increase in RR	% Species showing no change	No. Spp
Channel Country	CHC	36	44	20	144	40	36	24	53
Mulga Lands	ML	39	36	25	176	36	36	28	78
Broken Hill Complex	BHC	35	48	17	157	21	61	18	62
Australian Alps	AA	58	25	17	131	51	22	27	72
Riverina	RIV	39	41	21	232	47	31	22	104
Cobar Peneplain	CP	42	28	30	230	36	36	28	109
Simpson-Strzelecki Dunefields	SSD	29	48	23	149	23	63	14	56
NSW Southwestern Slopes	NSS	31	41	28	264	34	37	29	126
South Brigalow	BBS	34	39	27	258	24	42	34	121
Murray-Darling Depression	MDD	46	30	24	204	40	31	29	94
Darling Riverine Plains	DRP	21	53	26	232	24	40	36	106
South Eastern Highlands	SEH	48	27	25	253	40	30	30	110
Nandewar	NAN	42	37	21	233	49	27	24	117
South East Corner	SEC	45	28	27	229	50	19	31	90
New England Tableland	NET	44	31	25	246	32	37	31	113
NSW North Coast	NNC	29	47	24	303	32	39	29	109
Sydney Basin	SB	37	32	31	306	28	33	39	119
Average no. species		39	37	24	220	36	36	28	96

Selection of data for analysis

As there were substantial differences between survey design and survey protocols between the two atlases, it was necessary to restrict data so that the two atlases were as comparable as possible. The data screening process adopted was as follows:

- Surveys were stratified by 1° grid and the comparison between *Atlas 1* and *Atlas 2* was then matched by grid. There were 10,278 *Atlas 1* surveys and 15,193 *Atlas 2* surveys included in the analysis, with an average of 23 species per survey for both atlases (Figure 4a and b).
- Only 1° grids with at least 5 surveys from both atlases were compared (82 grids).
- Only surveys completed within a single 24 hr period were included.
- Only 500 m and 5 km searches from *Atlas 2* were compared with 10 minute grid searches from *Atlas 1*.
- The surveys were spread across the four seasons. *Atlas 1* (total 10,278 surveys): summer 2,447 (24%); autumn 2,349 (23%); winter 2,636 (26%) and spring 2,846 (27%). *Atlas 2* (total 4,382 surveys): summer 3,097 (21%); autumn 3,842 (25%); winter 3,872 (25%) and spring 4,382 (29%).
- Only bird species recorded at least 30 times in both atlases (combined) were compared. This data filter was put in place after the previous filters described above. As a result, 347 bird species were included in the comparison.
- Species whose taxonomy had changed were lumped or split according to their new classification (Christidis and Boles 1994). White's Thrush has been split into two species, the Bassian (*Zoothera lunulata*) and Russet-tailed Thrush (*Zoothera heinei*), and because the range of these two new species overlaps, neither species could be included in the analysis.

Results

Statewide trends

Of 347 bird species tested, 80 (23%) were recorded less frequently during *Atlas 2* (declining species), 83 (24%) were recorded more frequently during *Atlas 2* (increasing species), and 184 species (53%) showed no change between the two atlases (Table 3 see also Appendix 1). Of the 139 woodland species tested, 33 (24%) were recorded less frequently during *Atlas 2*, a similar proportion to that for all bird species (23%, Table 3). Thirty-six woodland bird species (26%) had increased

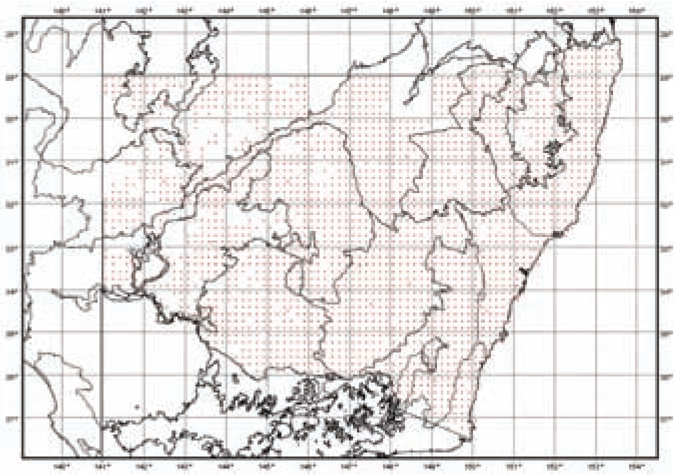

Figure 4a. Location of 10,278 NSW *Atlas 1* surveys within each IBRA bioregion and within each 1° grid. A dot is placed in the centre of each 10-minute grid representing the distribution of the surveys included in the comparison.

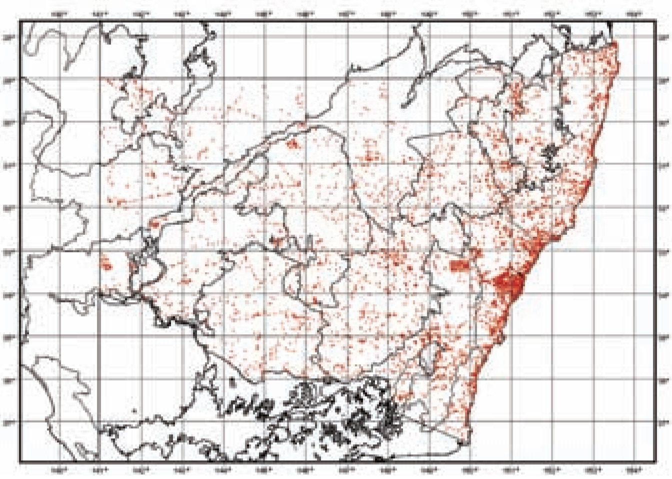

Figure 4b. Location of 15,193 NSW *Atlas 2* surveys within each IBRA bioregion and within each 1° grid. Each dot represents an individual survey.

reporting rates in *Atlas 2* and 70 species showed no change (Table 3). Woodland birds represented 41% of the declining species (33/80 species) and a similar proportion (43%) of the increasing species (36/83 species, Table 3). Of the 184 species that showed no significant change in reporting rate, 70 species (38%) were woodland birds (Table 3, see also Appendix 1).

IBRA bioregions

There was significant regional variation ($p<0.05$) in the way the reporting rate changed between *Atlas 1* and *Atlas 2* for 131 species (38%, Appendix 1, Tables 1-3). That is to say, for a given species, the reporting rate increased in some parts of NSW but decreased in others. The remaining 216 species showed no regional variation, i.e. the change in reporting rate or lack of change in reporting rate was uniform throughout the species' range (Appendix 1, Tables 4-6). As an example, the Diamond Firetail showed a 39% decline in reporting rate across NSW in *Atlas 2* but also showed significant regional variation in the change in reporting rate between the two atlases (Appendix 1, Table 1, $p<0.01$). The analysis of individual IBRA bioregions showed a 69% decrease in reporting rate for Diamond Firetails in the Australian Alps, a 21% decrease in the South Brigalow, 23% decrease on the Cobar Peneplain and so on (Electronic Appendix, Tables 1, 2 and 5). The change map for the Diamond Firetail (one of 18 species presented in this

Table 3. Summary of changes between *Atlas 1* (1977-1981) and *Atlas 2* (1998- 2001) for 347 NSW bird species. Regional Variation means that the change in reporting rate between *Atlas 1* and *Atlas 2* varied significantly between IBRA bioregions ($p\leq 0.05$). That is to say, reporting rates increased in some bioregions but decreased in others.

Variation between IBRA Bioregions	Changes in reporting rate between *Atlas 1* and *Atlas 2*	No. Species (% of the 347 species tested)
Regional Variation (131 species)	Decliners (Appendix 1, Table 1)	36 species (10%)
	Increasers (Appendix 1, Table 2)	14 species (4%)
	No change (Appendix 1, Table 3)	81 species (23%)
No Regional Variation (216 species)	Decliners (Appendix 1, Table 4)	44 species (13%)
	Increasers (Appendix 1, Table 5)	69 species (20%)
	No change (Appendix 1, Table 6)	103 species (30%)
Woodland bird species	Decliners	33 species (24%)
	Increasers	36 species (26%)
	No change	70 species (50%)
	Total no. species	**139 species**
All bird species	Decliners	80 species (23%)
	Increasers	83 species (24%)
	No change	184 species (53%)
	Total no. species	**347 species**

way) indicates that this species has decreased across a large area of central and southern NSW (Appendix 3, Figure 6). Individual bird species showed a range of patterns. There were those recorded less frequently throughout their range, such as the Black-faced Woodswallow, Chestnut-crowned Babbler, Cockatiel, Restless Flycatcher and Scarlet Robin (Appendix 3, Figures 1, 3, 4, 12 and 14), and species such as the Little Corella, Noisy Friarbird and Superb Fairy-wren, which showed increased reporting rates throughout most of their range (Appendix 3, Figures 9, 10 and 16). Some species such as the Zebra Finch, showed increased reporting rates across most of their range, yet declined in their core bioregions, resulting in an overall decline in reporting rate for the species (Appendix 1, Table 1, Appendix 3, Figure 18).

Drivers of regional variation

The proportion of woodland bird species that had declined (by at least 20%) within a bioregion was negatively correlated with the proportion of species that had increased (by at least 20%) within a bioregion (Table 2, Appendix 4, $r = -0.925$, $p<0.01$). That is to say, bird species tended to have declined in different bioregions to those in which bird species had tended to increase. IBRA bioregions with extensive native vegetation were negatively associated with the total number of woodland bird species (Tables 1 and 2, Appendix 4, $r = -0.934$, $p<0.01$, also true for all bird species combined, $r = -0.840$, $p<0.01$). This was illustrated by the above average number of woodland species in bioregions with relatively low native vegetation cover such as the NSW Southwestern Slopes (126 species) and South Brigalow (121 species, Tables 1 and 2, Figure 3). Although not significant, these bioregions also indicate a positive association between the number of woodland bird species and increased rainfall during *Atlas 2* (Tables 1 and 2, Appendix 4, $r = 0.407$, $p>0.05$, Figure 1).

The proportion of woodland bird species that had increased reporting rate during *Atlas 2* was greater in bioregions where the landscape was dominated by livestock grazing (Tables 1 and 2, Appendix 4, $r = 0.486$, $p<0.05$). It should be noted though, these extensively grazed landscapes tended to have received greater levels of rainfall (Table 1, Figure 1, Appendix 4, $r = 0.5$, $p<0.05$). A number of declining bird species were recorded less frequently in stressed bioregions such as the NSW Southwestern Slopes, Murray-Darling Depression and South Eastern Highlands, these include the Chestnut-crowned Babbler, Diamond Firetail, Jacky Winter, Restless Flycatcher, Scarlet Robin and Southern White-face (Figure 2, Appendix 3, Figures 3, 6, 8, 12, 14 and 15). Furthermore, the proportion of woodland species that showed a greater than 20% decline in reporting rate was well above the average of 36% in relatively undisturbed bioregions such as the Australian Alps (51%), South East Corner (SEC, 50%) and Nandewar (NAN, 49%, Table 2).

Modelling of individual species

Of 139 woodland bird species considered (Appendix 1, Tables 1-6), 45 were ignored because they occurred in fewer than ten IBRA bioregions. For a further 67 species, no significant variables were selected, or the models were unstable and rejected. Significant models were generated for the remaining 27 species (Tables 4 and 5). The proportion of native vegetation was the most frequently selected predictor of changes to reporting rate for individual bird species (Table 5). However, the changes to reporting rate were both positively (7 cases) and negatively (6 cases) associated with the proportion of native vegetation in the bioregion. Increaser bird species (that had increased reporting rates across NSW, Appendix 1) tended to show a reduced reporting rate in bioregions with extensive native vegetation cover, as demonstrated by the Golden Whistler, Yellow-faced Honeyeater and Noisy Friarbird (Table 4), while species that had declined or shown no change across NSW, tended to show increased reporting rates in such bioregions, as demonstrated by the Cockatiel, Flame Robin, White-browed Woodswallow, Rainbow Bee-eater, Red-capped Robin, Southern Whiteface and Yellow-throated Miner (Table 4).

The proportion of the bioregion grazed by livestock was the second most frequently selected environmental predictor of changes to reporting rate for individual woodland bird species. Like native vegetation, this predictor had both a positive and negative influence (Tables 4 and 5). The proportion of a bioregion impacted by grazing stock was positively associated with two species that had shown increased reporting rates across NSW (Australian King Parrot and Eastern Yellow Robin), as well as one species that showed no change across NSW (Superb Fairy-wren) and one species that had declined across NSW (Yellow-rumped Thornbill, Table 4). By contrast, the percent area grazed was negatively associated with three species that had shown no change across NSW (Pallid Cuckoo, White-breated Woodswallow and Black-chinned Honeyeater) and one species that had declined across NSW (Black-faced Woodswallow). The composite measure of landscape stress showed little relation to changes reporting rate for woodland birds, being positively associated with one species that showed no change in reporting rate across NSW (Fuscous Honeyeater), and negatively associated with White-throated Gerygones which showed an increased reporting rate across NSW (Table 4).

Bioregions with greater rainfall during *Atlas 2* compared with *Atlas 1*, were associated with increased reporting rates for four woodland bird species (Southern Boobook, Grey-crowned Babbler, Blue-faced Honeyeater and Eastern Yellow Robin, Table 4). Rainfall was also positively associated with greater overall bird diversity (Tables 1 and 2, Appendix 4, $r = 0.486$, $p<0.05$). Although rainfall was not selected as a significant predictor, a trend towards increased reporting rate and increased rainfall appears to be true for species such as the Noisy Friarbird, Sacred Kingfisher, Superb Fairy-wren and Zebra Finch (Appendix 3 Figures 10, 13, 16 and 18).

Table 4. Regression models for changes in reporting rates (RR) between IBRA bioregions (n=17), for woodland bird species. Change in RR was defined as (RR *Atlas 1* – RR *Atlas 2*)/RR *Atlas 1*. For species identified as declining, increasing or showing no change in RR across NSW, see Appendix 1 (Tables 1 to 6). Only species recorded in at least 20 surveys in both atlases, and recorded in at least 10 IBRA bioregions were included, and only significant models are presented ($p \le 0.05$). Transformations (either square root or log) and significant interactions are identified in brackets with each species.

Woodland bird species that declined in NSW (32 species, Appendix 1): (8 species ignored because occurred in fewer than 10 IBRA bioregions, no significant variables were selected for 17 species, significant models produced for 7 species)

	Significant variables	Estimate	Std Error	*t*	*p*	% Var
Cockatiel (sqrt)	Constant % Native vegetation	+ 0.99 + 0.10	2.92 0.04	− 0.34 2.47	0.74 0.03	27
Southern Boobook (sqrt)	Constant Rainfall wetter or much wetter	+ 0.51 + 3.32	0.88 1.2	5.8 2.76	<0.001 0.016	32
Flame Robin	Constant % Native vegetation	− 110.9 + 1.27	37.1 0.58	− 2.99 2.19	0.014 0.053	26
Yellow-rumped Thornbill (sqrt)	Constant % Grazed area	+ 2.91 + 0.07	1.63 0.02	1.79 3.61	0.094 0.003	43
White-browed Woodswallow (sqrt)	Constant % Native vegetation	+ 0.82 + 0.07	2.10 0.03	0.39 2.47	0.702 0.028	27
Black-faced Woodswallow ($\log_{10}$)	Constant % Grazed area	+ 4.48 − 0.04	1.39 0.02	3.22 − 2.36	0.008 0.037	28
Dusky Woodswallow	Constant % Native vegetation	+ 4.2 − 0.7	11.4 0.16	0.36 − 4.34	0.721 <0.001	56
Species showing no significant change in NSW (74 species, Appendix 1): (25 species ignored because occurred in fewer than 10 IBRA bioregions, no significant variables were selected for 36 species, significant models produced for 14 species)						
Glossy Black-Cockatoo	Constant % Native vegetation	+ 88.0 − 1.53	33.4 0.52	2.63 − 2.92	0.03 0.019	46
Rainbow Bee-eater (sqrt)	Constant % Native vegetation	+ 2.14 + 0.09	2.53 0.04	0.85 2.52	0.411 0.025	26
Leaden Flycatcher	Constant % Native vegetation	+ 68.2 − 1.16	17.7 0.3	3.84 − 3.89	0.005 0.005	61
Pallid Cuckoo (sqrt)	Constant % Grazed area	+ 15.76 − 0.12	2.73 0.03	5.77 − 3.50	<0.001 0.003	41
Red-capped Robin (sqrt)	Constant % Native vegetation	+ 0.59 + 0.09	2.89 0.04	0.20 2.35	0.842 0.035	24
Grey-crowned Babbler (sqrt)	Constant Rainfall wetter or much wetter	+ 5.12 + 4.70	1.12 1.48	4.59 3.18	<0.001 0.008	41
Southern Whiteface	Constant % Native vegetation	− 89.1 + 1.21	41.4 0.56	− 2.15 2.15	0.049 0.049	20
Superb Fairy-wren ($\log_{10}$)	Constant % Grazed area	+ 0.30 + 0.02	0.28 0.004	1.07 5.78	0.309 <0.001	73
White-breasted Woodswallow (sqrt)	Constant % Grazed area	+ 31.86 − 0.28	5.85 0.07	5.44 − 4.00	<0.001 0.002	54
Black-chinned Honeyeater	Constant % Grazed area	− 111.4 − 1.5	50.7 0.6	2.26 − 2.48	0.054 0.038	37
Fuscous Honeyeater	Constant (Reference level 1-2) Landscape stress level 3 Landscape stress levels 4 to 6	− 68.9 + 89.6 + 76.6	11.4 15.1 16.1	− 6.05 6.0 4.8	<0.001 <0.001 0.002	80
Yellow-throated Miner	Constant % Native vegetation	− 83.1 + 0.99	22.0 0.29	− 3.78 3.38	0.005 0.01	54
Blue-faced Honeyeater (sqrt)	Constant Rainfall wetter or much wetter	+ 4.03 + 6.42	1.51 1.85	2.66 3.46	0.024 0.006	50

Species that increased in NSW (33 species, Appendix 1): (12 species ignored because occurred in fewer than 10 IBRA bioregions, no significant variables were selected for 15 species, significant models produced for 6 species)						
Australian King Parrot (sqrt)	Constant	+ 2.73	2.21	1.24	0.251	63
	% Grazed area	+ 0.12	0.03	4.01	0.004	
Eastern Yellow Robin (sqrt, interaction)	Constant	+ 1.30	1.01	1.29	0.229	86
	% Grazed area	+ 0.09	0.01	6.50	<0.001	
	Rainfall wetter or much wetter	+ 2.09	0.69	3.04	0.014	
Golden Whistler	Constant	+ 71.7	29.7	2.42	0.034	31
	% Native vegetation	− 1.15	0.46	− 2.53	0.028	
White-throated Gerygone	Constant (Reference level 1)	+ 303.9	24.6	12.4	<0.001	93
	Landscape stress levels 2 to 6	− 279.4	26.0	− 10.7	<0.001	
Yellow-faced Honeyeater	Constant	+ 86.6	23.5	3.69	0.005	50
	% Native vegetation	− 1.28	0.39	− 3.29	0.009	
Noisy Friarbird	Constant	+ 14.38	2.38	6.06	<0.001	29
	% Native vegetation	− 0.09	0.04	− 2.42	0.034	

Table 5. Number of times each variable was selected as a significant predictor of changed reporting rates between IBRA bio-regions for individual woodland bird species (models in Table 4).

Woodland bird group	Significant response	% Native vegetation	Landscape Stress	% Area impacted by grazing	Rainfall in *Atlas 2* compared with *Atlas 1*
Species that declined in NSW	+ ve	3	0	1	1
	− ve	1	0	1	0
Species showing no significant change in NSW	+ ve	4	1	1	2
	− ve	2	0	4	0
Species that increased in NSW	+ ve	0	0	2	1
	− ve	3	1	0	0
Total	+ ve	7	1	4	4
	− ve	6	1	5	0

Discussion

The analysis of change in reporting rate was based on large sample sizes for both *Atlas 1* and *Atlas 2* and represents a robust statistical result, however, the results should be interpreted with caution. Provided here is a snapshot of change, based on a comparison of two points in time 20 years apart and so observed changes are confounded by a range of factors such as climate fluctuations, temporal patterns in land use and different survey methods. As mentioned, there is also the potential for bias introduced by varying survey effort for particular threatened or sought-after species between the two atlases. By restricting the analysis to species that were recorded in at least 30 surveys (both atlases combined) the result is more reliable but as a consequence, some of the rarer species such as the Plains-wanderer (*Pedionomus torquatus*) and Grey Falcon (*Falco hypoleucos*) were excluded. As the national on-going atlas continues, an analysis of population trends will allow an increasingly comprehensive and accurate assessment of the conservation status of all Australian birds.

Comparison with national trends

Almost a quarter (23%) of the 347 bird species tested showed a decrease in reporting rate in NSW during *Atlas 2* compared with *Atlas 1* (Table 3), considerably larger than the 15% of bird species that declined nationally over the same period (Barrett *et al.* 2002). This trend towards there being more declining bird species in NSW is illustrated by a number of honeyeater species that are known to have increased nationally ($p<0.05$), such as the Yellow-plumed Honeyeater (19% increase), Brown-headed Honeyeater (30% increase), New Holland Honeyeater (80% increase, Barrett *et al.* 2003), yet showed no change or were less likely to be recorded during *Atlas 2* in NSW; Yellow-plumed Honeyeater (12% decrease, $p>0.05$), Brown-headed Honeyeater (11% decrease, $p>0.05$) and New Holland Honeyeater (8% decline, $p>0.05$, Appendix 1, Tables 3 and 6). The greater proportion of declining bird species in NSW relative to the rest of Australia will in part be due to much of this state being within Australia's intensive agricultural zone (NLWRA 2001). It is interesting to note that the Noisy Miner, an aggressive native honeyeater associated with bioregions such as the NSW Southwestern Slopes (NSS) where there has been extensive clearing and fragmentation of woodland habitat (Seddon *et al.* 2001), showed an increase in NSW (15% increase, $p<0.01$, Appendix 1, Table 5) but no significant increase nationally (Barrett *et al.* 2002). The greater proportion of declining bird species in NSW will also be due to the relatively low rainfall in that state during *Atlas 2* compared with the rest of Australia (http://www.longpaddock.qld.gov.au/RainfallAndPastureGrowth/NSW/index.html; Garnett *et al.* 2002). See below for discussion of modelling results where rainfall was a significant predictor of increased reporting rate for individual species. For examples of bird movements in response to seasonal patterns at different scales, see Griffioen (2001).

Woodland birds

The proportion of woodland bird species found to be declining (24%) or increasing (26%) was similar to that for the whole NSW bird assemblage (23% and 24% respectively, Table 3), suggesting that woodland birds have not suffered disproportionately. This was also reflected in there being a similar proportion of woodland species within those found to be declining (33/80 species, 41%) or increasing (36/83 species, 43%, Table 3). It may be that our working definition of woodland birds could be restricted to a smaller group of more typical woodland species. However, the problem with departing from our broader definition, which includes 139 bird species frequently associated with temperate woodland and open-forest habitats, is that we risk a circular argument in which woodland birds known to be declining are considered more typical of woodland habitats. Species that could be described as typical woodland birds were certainly well represented among the decliners, such as the Scarlet Robin, Varied Sittella, Restless Flycatcher, Dusky Woodswallow, Diamond Firetail, Hooded Robin, White-winged Triller and White-winged Chough. However, other equally typical woodland species increased over the same period, such as the Common Bronzewing, Musk Lorikeet and Striated Pardalote, or showed no significant change, such as the Brown Treecreeper, White-throated Treecreeper, Southern Whiteface, Jacky Winter, Sacred Kingfisher. This pattern of avian winners and losers, in response to agricultural intensification and urbanization in Australia, has been described by other researchers (Saunders and Curry 1990; James *et al.* 1999; Tait *et al.* 2005). Of the 20 woodland species identified by Reid (1999) as likely to be threatened in the near future, 19 were able to be analysed at the state level. Of these, eight were identified in the current study as decliners (having declined significantly across NSW, $p<0.05$, Appendix 1, Tables 1 and 4), they were the Emu, Restless Flycatcher, Dusky Woodswallow, Hooded Robin, Varied Sittella, Crested Shrike-tit, Diamond Firetail and White-browed Woodswallow. Two species, the Eastern Yellow Robin and White-browed Babbler, were defined as increasers (Appendix 1, Table 5), and nine species, the Painted Button-quail*, Brown Treecreeper*, Speckled Warbler, Rufous Whistler*, Grey-crowned Babbler, Crested Bellbird, Jacky Winter*, Red-capped Robin* and Southern Whiteface*, showed no significant change in reporting rate, although for six of these (with asterisk), the trend was towards their being less frequently recorded (Appendix 1, Tables 3 and 6, Appendix 3, Figures 2, 6, 7, 8, 12, 13, 15 and 17).

Setting conservation priorities– A case study

The IUCN (2001) definition of a vulnerable species is one that has undergone a reduction in population size of ≥30% over the last ten years or three generations, whichever is longer (based on an index of abundance appropriate to the taxon), where the reduction or its causes may not have ceased OR may not be understood OR may not be reversible. Of the 347 bird species analysed, 56 showed a decline in reporting rate of 30% or more in NSW (Appendix 1, Tables 1 and 4). Of these 56 species, 15 (27%) were woodland birds. The Gang-gang Cockatoo provides a specific example of how the data presented here may be used to assist in setting conservation priorities. With an overall reporting rate that has declined by a statistically significant 44% between atlassing periods (Appendix 1, Table 4), this species meets the IUCN criteria for vulnerable species. This overall trend comprised of reductions in the Australian Alps, NSW Southwestern Slopes, Sydney Basin, South East Corner and South Eastern Highlands Bioregions (Electronic Appendix, Tables 1, 12, 14, 15 and 16 respectively). There were increases in the Nandewar and NSW North Coast Bioregions (Electronic Appendix, Tables 9 and 11) but these increases were based on few data and in bioregions at the northern limit of the species' range. Gang-gang Cockatoos have also been recorded as increasing in the ACT (Taylor 1992). The Gang-gang Cockatoo is easy to detect and identify and the records of the bird observers who contributed to the Birds Australia atlases were likely to be reliable for the species. Hence, the decline in reporting rates was considered by the Department of Environment and Climate Change (DECC) to be an appropriate index of the declining numbers for the Gang-gang Cockatoo in NSW. There are no data for the generation length (average breeding age) of the Gang-gang Cockatoo but they are likely to breed at four years of age (Higgins 1999). The Galah, a similar but slightly larger cockatoo, breeds at three years of age, and demographic data for this species in south-western Western Australia show that it must breed beyond 11 years of age to maintain population numbers (Rowley 1990). Assuming this also applies to the Gang-gang Cockatoo, based on an average generation length of eight years, three generations is estimated to be 24 years. This preliminary assessment of the Gang-gang Cockatoo against the IUCN criterion, suggesting a 44% decline in reporting rate over two decades (2.5 generations), contributed to the recent listing of the Gang-gang Cockatoo as a Vulnerable species in NSW (http://www.nationalparks.nsw.gov.au/npws.nsf/Content/gang-gang_cockatoo_vulnerable). While the cause of the decline is unknown, the species is dependent on large hollows for breeding (Higgins 1999) and this resource is in decline (see discussion below).

Bioregional variation

Our study highlights the importance of regional variation in assessing changes to reporting rates for bird species. Over one third (38%) of the 347 species tested showed significant regional variation in the change to their reporting rate and interestingly, bird species that had undergone a decline in reporting rate (of at least 20%) within bioregions, tended to occupy different parts of the landscape to those that had undergone an increase in reporting rate (of at least 20%) within bioregions (Table 2, Appendix 4). Models identifying possible relationships between changes in reporting rates and the four bioregional features tested (% native vegetation, % grazed area, landscape stress and rainfall) were only generated for 27 of a potential 95 species, highlighting the limitations of our modelling analysis and suggesting that other environmental features may also be driving species reporting rates. Each environmental predictor is discussed here in relation to the modelling results (Table 4), and in relation to the broader comparison of reporting rates between the two atlases across NSW (Appendix 1), and also in relation to changes within each bioregion (Electronic Appendix).

% native vegetation

The negative association between the number of woodland bird species and the proportion of native vegetation in a bioregion (Table 2, Appendix 4, $r = -0.934$, $p<0.01$) contrasts with research which identifies native vegetation cover as a primary predictor of woodland bird diversity. For example, Bennett and Ford (1997) and Radford *et al.* (2005) identify a 10% native woody vegetation cover threshold in Victoria, below which woodland bird diversity declined dramatically. The inconsistency between our results and this much more intuitive result can be partly explained by the NLWRA definition of native vegetation which includes non-woody plants. Also, while not significant, there was a trend towards increased rainfall in areas with less native vegetation, which would attract birds into these biorgeions (Tables 1 and 2, Appendix 4, $r = -0.338$, $p > 0.05$).

The modelling results suggest that declining bird species (that had reduced reporting rates across NSW) and bird species showing no change across NSW, were more likely to have had increased reporting rates in bioregions with a greater proportion of native vegetation (Tables 4 and 5). By contrast, species that had increased across NSW were less likely to have shown increased reporting rates in bioregions with a greater proportion of native vegetation. With estimates of up to 10 million hectares of native woody vegetation cleared over the 20-year period between the two atlases (mostly in NSW and Queensland, DEST 1995), habitat loss and fragmentation into small, isolated patches is likely to have contributed to the declining reporting rates of species that tend to occur in larger patches of woodland, such as the Grey Currawong, Crested Shrike-tit, Hooded Robin, Satin Flycatcher and Wedge-tailed Eagle (Appendix 1). Large open-country species such as the Crested Pigeon and Long-billed Corella, and larger woodland species such as the Common Bronzewing Grey Butcherbird, Pied Currawong, Yellow-tailed Black-Cockatoo, Australian King Parrot and Torresian Crow, all showed increased reporting rates (Appendix 1) and are likely to have been favoured by the loss and fragmentation of woodland habitat (Barrett *et al.* 1994; Howe 1986; Dow 1977; Loyn 1987; Ryan 1999).

Landcare and similar community initiatives have resulted in small increases in the amount of native vegetation through revegetation programs over the last 20 years (Freudenberger and Harvey 2003), and there is evidence that increasing woodland species that depend on low, dense vegetation, such as the Common Bronzewing, Eastern Yellow Robin, White-browed Babbler, Variegated Fairy-wren, White-browed Scrubwren and Brown Thornbill, are returning to rural landscapes as a consequence of these revegetation activities (Ryan 1999; Taws 2000; Fisher 2001; Majer *et al.* 2001). Increased horticultural activity and an increase in fruit and berry-producing plants are likely to have resulted in an increase in fruit-eating birds such as the Satin Bowerbird, Scaly-breasted Lorikeet, Silvereye and Yellow-tailed Black-Cockatoo, particularly along urban fringes (Bass 1990; Catterall *et al.* 1991; Grover and Slater 1994; Catterall *et al.* 1997; Mills 1997; Olsen *et al.* 2003). While exotic species such as the Common Starling, European Greenfinch, European Goldfinch and House Sparrow were recorded less frequently, suggesting that such species have concluded their expansion and colonization phase and are reaching equilibrium within Australian landscapes, other exotic species such as the Spotted Turtle-Dove, Common Blackbird and Common Myna are still increasing (Appendix 1, Tables 2 and 4, Appendix 3, Figure 5). For overviews of changes to bird assemblages in NSW agricultural landscapes and possible causes for change, see Goldney and Bowie (1990), Barrett *et al.* (1994), Robinson and Traill (1996), Bennett *et al.* (1998), Garnett and Crowley (2000), Ford *et al.* (2001), Platt (2001), Martin and Green (2002), Lindenmayer *et al.* (2003), Seddon *et al.* (2003) and Watson *et al.* (2003).

% Grazed area

As with the amount of native vegetation within a bioregion, the proportion of grazed area within the bioregion was both positively and negatively associated with changes to reporting rates for individual bird species (Table 5). Declining reporting rates, particularly of ground-foraging insectivores such as the Magpie-lark, Laughing Kookaburra, White-winged Chough, Richard's Pipit, Flame Robin, Hooded Robin, Scarlet Robin, Singing Bushlark, Spotted Quail-Thrush and Yellow-rumped Thornbill (Appendix 1, Tables 1 and 4), are likely to be associated with heavy grazing by livestock (Baker-Gabb *et al.* 1989; Johnson and Baker-Gabb 1994; Reid *et al.* 1997; Barrett 2000; Grover and Slater 1994; Landsberg *et al.* 1997; Yates *et al.* 2000; James 2003). The replacement of native perennial pastures with annual grasses, typical of intensive land use in temperate regions, is also likely to have led to a loss of ground-foraging birds (Davidson and Davidson 1992; Barrett *et al.* 1994; Lindenmayer *et al.* 2003). In semi-arid landscapes, grazing pressure from livestock and feral species such as goats may partly explain decreased reporting rates for bird species such as the woodswallows, White-winged Triller, Orange Chat, White-backed Swallow, Red-backed Kingfisher, Spotted Harrier, White-fronted Chat, White-winged Fairy-wren and Zebra Finch (Landsberg *et al.* 1997; Wilson 1997; James *et al.* 1999; Yates *et al.* 2000; James 2003). Reporting rates for four woodland bird species increased in bioregions that show extensive grazing, they are the Australian King Parrot, Eastern Yellow Robin, Superb Fairy-wren and Yellow-rumped Thornbill (Table 4). This positive association with grazing supports the view that there is a link between increased bird diversity and moderate levels of grazing by livestock (Barrett and Davidson 1999; Lindenmayer *et al.* 2003), but may also be due to the fact that bioregions with extensive grazing received more rainfall during *Atlas 2* (Table 1, Appendix 4, r = 0.5, $p<0.05$). Note there was a significant interaction between % grazed area and rainfall for the Eastern Yellow Robin (Table 4).

Landscape stress

The relatively minor influence of landscape stress on the predictive models for individual bird species may be partly due to the LWRA measure of landscape stress being a composite measure that subsequently had less influence than more direct measures, such as native vegetation cover and grazed area. Although not significant, some bird species appear to be favoured by agricultural intensification. For example, large honeyeaters such as the Noisy Friarbird, Noisy Miner and Red Wattlebird, that were recorded more frequently in bioregions with greater landscape stress and less native vegetation cover, such as the NSW Southwestern Slopes and Murray Darling Depression (Figures 2 and 3, Electronic Appendix, Appendix 3, Figure 10). However, agricultural intensification has been widely identified as a cause of decline in Australia's temperate woodland birds (Wilson and Willis 1975; Saunders 1989; Saunders and Curry 1990; Bauer and Goldney 1999; Possingham 2000), and is associated with a loss of specific habitats such as mature trees and the range of ecological services they provide (Ozlins *et al.* 2001; Fischer and Lindenmayer 2002a, b; Gibbons and Boak 2002; Manning 2006). An estimated 15% of all bird species, including decling species such as the Gang-gang Cockatoo, Laughing Kookaburra and Tree Martin use tree hollows for breeding (Gibbons and Lindenmayer 2002).

Rainfall

It is possible that the six month lag time applied to the rainfall data overly reduced the influence of this variable as a predictor (Garnett pers. com.). Our results do, however, support the notion that bird numbers and diversity are broadly associated with increased rainfall in Australian landscapes (Nix 1976; Woinarski and Braithwaite 1990). Flowering events following favourable rainfall conditions drive the nomadic and opportunistic behaviour of many nectivorous and frugivorous bird species (Keast 1968; Ford *et al.* 1990; Mac Nally 1990; Neave *et al.* 1996), and will partly explain the increased reporting rates for species such as the Musk Lorikeet, Scaly-breasted Lorikeet, Scarlet Honeyeater, Striped Honeyeater, White-fronted Honeyeater and Yellow-faced Honeyeater (Appendix 1, Tables 2 and 5 and Electronic Appendix). Coastal forest species such as the Eastern Yellow Robin, Figbird, Noisy Pitta, Olive-backed Oriole, Satin Bowerbird, White-browed Scrubwren, White-headed Pigeon and Pheasant Coucal (Appendix 1, Tables 2 and 5), also showed increased reporting rates, particularly in bioregions with greater rainfall (Figure 1, Table 1). For a comprehensive overview of seasonal patterns of movement in Australian birds using atlas data, see Griffioen (2001) and Griffioen and Clarke (2002).

Conclusion

Although much of NSW is within Australia's intensive agricultural zone, there were as many increasing bird species as there were declining species, a pattern described by other authors for birds in agricultural landscapes (Saunders 1989; Barrett *et al.* 1994; Watson *et al.* 2000; Seddon *et al.* 2003). Furthermore, the proportion of woodland-dependent species was similar among both increasers and decreasers and, despite clear differences in native vegetation cover, area impacted by grazing stock, rainfall and landscape stress, declining species occurred in all bioregions. Nomadic species such as the woodswallows illustrate why this might be so. After spending the winter months in Australia's central arid regions, woodswallows move into the stressed agricultural regions of the temperate woodlands to breed. Robinson and Traill (1996) have suggested that this vulnerable breeding period is likely to have caused woodswallows to decline across their range (including bioregions that have not been heavily impacted by agriculture).

The models of change to reporting rate indicate that no single bioregional feature had an over-riding influence. Rather, there appears to be an interplay between the environmental features studied, each being off-set or enhanced by another. Much detail was lost by averaging the predictor variables across subregions and the utility of the NLWRA data set would be greatly enhanced by analyzing data at a subregional scale. A continuing challenge is to sort out responses to short-term factors such as rainfall from longer term factors such as grazing impacts, and there is much to be gained from a more detailed analysis of individual species or functional groups. In the absence of continuous long-term trend data, this study of two points in time provides a preliminary assessment of the status of NSW bird species over the last 20 years. Our our results also demonstrate the potential for national databases such as the bird atlas and the NLWRA *Landscape Health in Australia* database, to assist wildlife agencies and Natural Resource Management groups in setting priorities for bird conservation.

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Appendix 1: Comparison of 347 bird species.

Tables 1-6 show increasing species, declining species and species that showed no change, between *Atlas 1* (1977-1981) and *Atlas 2* (1998-2001).

Tables are divided into species that showed significant variation between NSW IBRA bioregions (Tables 1-3) and those that did not (Tables 4-6).

Regional Variation

Table 1. Bird species showing variation between NSW IBRA bioregions and, across the whole state, were recorded less frequently in *Atlas 2* compared with *Atlas 1* (36 species). * Indicates predictive model unstable, result may be inaccurate. ▼ Identifies species less likely to be recorded using the *Atlas 2* survey methods than those used in *Atlas 1*. ▲ Identifies species more likely to be recorded using the *Atlas 2* survey methods than those used in *Atlas 1*. No. Units = Number of 10-minute grids included in the analysis, RR = Adjusted Reporting Rate, % Change in Reporting rate between *Atlas 1* and *Atlas 2*. Shading identifies species likely to be associated with patches of woodland or open forest in the temperate or arid regions of NSW.

Declining species	Scientific Name	No. Units	Atlas 1 RR	Atlas 2 RR	% Change	p value
Plumed Whistling-Duck	*Dendrocygna eytoni*	90	0.02297	0.0112	-51.2	0.005
Great Cormorant	*Phalacrocorax carbo*	242	0.08853	0.0657	-25.8	0.036
White-faced Heron	*Egretta novaehollandiae*	278	0.25	0.1833	-26.7	0.002
White-necked Heron	*Ardea pacifica*	266	0.1403	0.0686	-51.1	<0.001
Glossy Ibis*	*Plegadis falcinellus*	120	0.02354	0.01432	-39.2	0.003
Yellow-billed Spoonbill	*Platalea flavipes*	224	0.07227	0.05315	-26.5	0.026
Spotted Harrier	*Circus assimilis*	176	0.04123	0.01871	-54.6	<0.001
Little Eagle	*Hieraaetus morphnoides*	236	0.05325	0.03265	-38.7	<0.001

APPENDIX I

Declining species	Scientific Name	No. Units	Atlas 1 RR	Atlas 2 RR	% Change	p value
Brown Falcon ▼	*Falco berigora*	280	0.1536	0.0915	-40.5	<0.001
Nankeen Kestrel ▼	*Falco cenchroides*	284	0.353	0.17	-51.8	<0.001
Red-kneed Dotterel	*Erythrogonys cinctus*	132	0.0401	0.02316	-42.3	0.022
Banded Lapwing	*Vanellus tricolor*	194	0.04172	0.02097	-49.7	<0.001
Masked Lapwing	*Vanellus miles*	272	0.2216	0.1584	-28.5	0.001
Cockatiel	*Nymphicus hollandicus*	214	0.10531	0.05495	-47.8	0.001
Red-backed Kingfisher	*Todirhamphus pyrrhopygia*	166	0.05375	0.02638	-50.9	<0.001
Dollarbird ▼	*Eurystomus orientalis*	176	0.07255	0.05716	-21.2	0.024
White-winged Fairy-wren	*Malurus leucopterus*	140	0.1294	0.1013	-21.7	0.035
White-fronted Chat	*Ephthianura albifrons*	156	0.0384	0.01845	-52.0	0.001
Scarlet Robin	*Petroica boodang*	116	0.08992	0.04088	-54.5	<0.001
Chestnut-crowned Babbler	*Pomatostomus ruficeps*	98	0.10995	0.07364	-33.0	0.046
Varied Sittella*	*Daphoenositta chrysoptera*	218	0.06355	0.03578	-43.7	<0.001
Restless Flycatcher	*Myiagra inquieta*	266	0.10933	0.0748	-31.6	0.023
Magpie-lark ▼	*Grallina cyanoleuca*	286	0.4963	0.4147	-16.4	0.005
Ground Cuckoo-Shrike	*Coracina maxima*	128	0.02853	0.01736	-39.2	0.001
Masked Woodswallow	*Artamus personatus*	154	0.04176	0.02243	-46.3	0.001
White-browed Woodswallow	*Artamus superciliosus*	224	0.09163	0.03561	-61.1	<0.001
Black-faced Woodswallow	*Artamus cinereus*	180	0.14622	0.0506	-65.4	<0.001
Dusky Woodswallow	*Artamus cyanopterus*	236	0.09592	0.05621	-41.4	0.007
Little Woodswallow*	*Artamus minor*	34	0.02458	0.01551	-36.9	0.036
Singing Bushlark	*Mirafra javanica*	140	0.03021	0.01528	-49.4	<0.001
Zebra Finch	*Taeniopygia guttata*	202	0.07818	0.05805	-25.8	0.008
Diamond Firetail	*Stagonopleura guttata*	160	0.07804	0.04761	-39.0	0.013
European Greenfinch	*Carduelis chloris*	266	0.11561	0.07723	-33.2	<0.001
White-backed Swallow	*Cheramoeca leucosternus*	160	0.04017	0.02196	-45.3	<0.001
Tree Martin	*Hirundo nigricans*	284	0.1283	0.0916	-28.6	<0.001
Common Starling ▼	*Sturnus vulgaris*	264	0.249	0.1628	-34.6	0.021

Table 2. Bird species showing variation between NSW IBRA bioregions and, across the whole state, were recorded more frequently in *Atlas 2* compared with *Atlas 1* (14 species). For an explanation of codes, see the caption for Table 1.

Increasing species	Scientific Name	No. Units	Atlas 1 RR	Atlas 2 RR	% Change	p value
Australasian Shoveler ▼	*Anas rhynchotis*	184	0.03252	0.05225	60.7	0.006
Darter ▼	*Anhinga melanogaster*	212	0.04206	0.06993	66.3	0.002
Royal Spoonbill	*Platalea regia*	170	0.03032	0.05098	68.1	0.046
White-bellied Sea-Eagle	*Haliaeetus leucogaster*	110	0.02982	0.05028	68.6	0.004
Pied Oystercatcher	*Haematopus longirostris*	36	0.04108	0.06649	61.8	0.031
Bar-shouldered Dove	*Geopelia humeralis*	112	0.02285	0.03408	49.2	0.041
Little Corella	*Cacatua sanguinea*	178	0.02199	0.0511	132.4	<0.001
Musk Lorikeet	*Glossopsitta concinna*	86	0.01329	0.03348	152.0	0
Channel-billed Cuckoo ▼	*Scythrops novaehollandiae*	76	0.01	0.01989	98.8	0.019
Striped Honeyeater	*Plectorhyncha lanceolata*	196	0.0702	0.09774	39.2	0.028
Noisy Friarbird	*Philemon corniculatus*	200	0.1079	0.1369	26.8	0.042
Australian Raven	*Corvus coronoides*	288	0.356	0.4177	17.3	0.002
Little Raven	*Corvus mellori*	174	0.04166	0.07848	88.4	0.001
Common Blackbird	*Turdus merula*	136	0.02859	0.04992	74.6	0.02

Table 3: Bird species showing variation between NSW IBRA bioregions and, across the whole state, showed no change in reporting rate between ***Atlas 2*** and ***Atlas 1*** (81 species). For an explanation of codes, see the caption for Table 1.

Species showing no change	Scientific Name	No. Units	Atlas 1 RR	Atlas 2 RR	% Change	p value
Stubble Quail	*Coturnix pectoralis*	142	0.01735	0.01931	11.3	0.493
Blue-billed Duck*	*Oxyura australis*	60	0.02368	0.03063	29.3	0.342
Black Swan	*Cygnus atratus*	234	0.1011	0.1257	24.2	0.075
Australian Wood Duck ▼	*Chenonetta jubata*	282	0.1887	0.2139	13.4	0.187
Pacific Black Duck ▼	*Anas superciliosa*	274	0.1894	0.1941	2.5	0.801
Grey Teal ▼	*Anas gracilis*	276	0.1733	0.1561	-9.9	0.274
Pink-eared Duck	*Malacorhynchus membranaceus*	166	0.03517	0.04683	33.2	0.09
Hardhead	*Aythya australis*	224	0.07451	0.0772	3.6	0.807
Australasian Grebe ▼	*Tachybaptus novaehollandiae*	262	0.1116	0.1351	21.1	0.094
Hoary-headed Grebe ▼	*Poliocephalus poliocephalus*	220	0.06346	0.06326	-0.3	0.984
Short-tailed Shearwater	*Puffinus tenuirostris*	30	0.03583	0.02311	-35.5	0.158
Little Pied Cormorant ▼	*Phalacrocorax melanoleucos*	266	0.1062	0.1321	24.4	0.122
Pied Cormorant	*Phalacrocorax varius*	186	0.03629	0.04985	37.4	0.067
Little Black Cormorant	*Phalacrocorax sulcirostris*	244	0.07005	0.09235	31.8	0.055
Australian Pelican	*Pelecanus conspicillatus*	232	0.09581	0.07463	-22.1	0.178
Great Egret	*Ardea alba*	220	0.06778	0.08639	27.5	0.159
Nankeen Night Heron	*Nycticorax caledonicus*	164	0.02	0.02495	24.7	0.192
Australian White Ibis	*Threskiornis molucca*	234	0.09498	0.09003	-5.2	0.814
Straw-necked Ibis	*Threskiornis spinicollis*	254	0.1182	0.1126	-4.8	0.691
Black-shouldered Kite ▼	*Elanus axillaris*	246	0.06604	0.0605	-8.4	0.646
Whistling Kite	*Haliastur sphenurus*	254	0.08543	0.07653	-10.4	0.475
Brown Goshawk ▼	*Accipiter fasciatus*	238	0.03863	0.03841	-0.6	0.958
Black Falcon*	*Falco subniger*	112	0.01963	0.01593	-18.8	0.241
Brolga	*Grus rubicunda*	60	0.02299	0.01602	-30.3	0.153
Baillon's Crake*	*Porzana pusilla*	38	0.007038	0.005633	-20.0	0.393
Purple Swamphen ▼	*Porphyrio porphyrio*	166	0.0699	0.07425	6.2	0.823
Dusky Moorhen ▼	*Gallinula tenebrosa*	206	0.06663	0.07143	7.2	0.806
Eurasian Coot ▼	*Fulica atra*	238	0.1176	0.1104	-6.2	0.592
Painted Button-quail*	*Turnix varia*	98	0.01868	0.0143	-23.5	0.186
Whimbrel	*Numenius phaeopus*	32	0.03514	0.03476	-1.1	0.968
Ruddy Turnstone	*Arenaria interpres*	30	0.010009	0.007434	-25.7	0.454
Sooty Oystercatcher	*Haematopus fuliginosus*	34	0.03254	0.03147	-3.3	0.89
Black-winged Stilt	*Himantopus himantopus*	188	0.06536	0.06355	-2.8	0.851
Lesser Sand Plover	*Charadrius mongolus*	22	0.01333	0.00884	-33.7	0.333
Black-fronted Dotterel	*Elseyornis melanops*	256	0.10116	0.07771	-23.2	0.087
Crested Tern	*Sterna bergii*	36	0.1862	0.1906	2.4	0.9
Common Tern	*Sterna hirundo*	24	0.02558	0.02471	-3.4	0.964
Little Tern*	*Sterna albifrons*	28	0.05071	0.0325	-35.9	0.367
Rock Dove	*Columba livia*	180	0.05957	0.05207	-12.6	0.529

APPENDIX 1

Species showing no change	Scientific Name	No. Units	Atlas 1 RR	Atlas 2 RR	% Change	p value
Diamond Dove	*Geopelia cuneata*	112	0.02692	0.03115	15.7	0.508
Galah ▼	*Cacatua roseicapilla*	282	0.4469	0.4281	-4.2	0.58
Sulphur-crested Cockatoo	*Cacatua galerita*	218	0.1228	0.1579	28.6	0.21
Eastern Rosella	*Platycercus eximius*	194	0.2038	0.2459	20.6	0.391
Blue Bonnet	*Northiella haematogaster*	178	0.1445	0.1142	-20.9	0.226
Red-rumped Parrot ▼	*Psephotus haematonotus*	244	0.1656	0.1104	-33.3	0.119
Mulga Parrot	*Psephotus varius*	118	0.05112	0.06321	23.7	0.325
Budgerigar	*Melopsittacus undulatus*	142	0.0424	0.03424	-19.2	0.271
Pallid Cuckoo	*Cuculus pallidus*	254	0.06169	0.05077	-17.7	0.086
Horsfield's Bronze-Cuckoo	*Chrysococcyx basalis*	268	0.05181	0.05593	8.0	0.398
Sacred Kingfisher	*Todirhamphus sanctus*	254	0.09451	0.09648	2.1	0.884
Rainbow Bee-eater ▼	*Merops ornatus*	254	0.07603	0.06791	-10.7	0.4
White-throated Treecreeper	*Cormobates leucophaeus*	168	0.1857	0.2344	26.2	0.265
Red-browed Treecreeper	*Climacteris erythrops*	76	0.03162	0.02182	-31.0	0.355
Brown Treecreeper	*Climacteris picumnus*	260	0.10455	0.08784	-16.0	0.393
Superb Fairy-wren	*Malurus cyaneus*	192	0.262	0.3257	24.3	0.076
Weebill	*Smicrornis brevirostris*	258	0.0936	0.1147	22.4	0.119
Chestnut-rumped Thornbill ▼	*Acanthiza uropygialis*	174	0.09201	0.10372	12.7	0.663
Southern Whiteface	*Aphelocephala leucopsis*	214	0.07185	0.05326	-25.9	0.084
Spiny-cheeked Honeyeater	*Acanthagenys rufogularis*	198	0.1223	0.1497	22.4	0.274
Blue-faced Honeyeater	*Entomyzon cyanotis*	182	0.04989	0.05947	19.2	0.234
Yellow-throated Miner	*Manorina flavigula*	172	0.2816	0.2331	-17.2	0.06
Lewin's Honeyeater	*Meliphaga lewinii*	84	0.09919	0.06924	-30.2	0.279
Singing Honeyeater	*Lichenostomus virescens*	170	0.1469	0.1367	-6.9	0.665
White-plumed Honeyeater	*Lichenostomus penicillatus*	266	0.2108	0.2173	3.1	0.807
Crimson Chat	*Ephthianura tricolor*	124	0.05728	0.03955	-30.9	0.074
Jacky Winter	*Microeca fascinans*	256	0.1506	0.1197	-20.5	0.279
Red-capped Robin ▼	*Petroica goodenovii*	222	0.0852	0.07913	-7.1	0.578
Rose Robin	*Petroica rosea*	98	0.01926	0.01941	0.8	0.966
Olive Whistler	*Pachycephala olivacea*	36	0.0297	0.02125	-28.4	0.396
Grey Shrike-thrush ▼	*Colluricincla harmonica*	280	0.273	0.3038	11.3	0.412
Grey Fantail	*Rhipidura albiscapa*	266	0.1904	0.2218	16.5	0.199
Willie Wagtail	*Rhipidura leucophrys*	286	0.4678	0.471	0.7	0.873
Varied Triller	*Lalage leucomela*	228	0.07909	0.08347	5.5	0.549
White-breasted Woodswallow	*Artamus leucorhynchus*	192	0.04732	0.0495	4.6	0.775
Pied Butcherbird	*Cracticus nigrogularis*	258	0.1387	0.164	18.2	0.183
Apostlebird	*Struthidea cinerea*	190	0.1217	0.0885	-27.3	0.182
Regent Bowerbird	*Sericulus chrysocephalus*	34	0.0188	0.01147	-39.0	0.186
Plum-headed Finch	*Neochmia modesta*	72	0.02363	0.01577	-33.3	0.1
Mistletoebird ▼	*Dicaeum hirundinaceum*	272	0.1161	0.1162	0.1	0.989
Welcome Swallow ▼	*Hirundo neoxena*	288	0.3412	0.3129	-8.3	0.123
Clamorous Reed-Warbler ▼	*Acrocephalus stentoreus*	218	0.05421	0.06288	16.0	0.456

No Regional Variation

Table 4. Bird species showing no variation between NSW IBRA bioregions and, across the whole state, were recorded less frequently in *Atlas 2* compared with *Atlas 1* (44 species). For an explanation of codes, see the caption for Table 1.

Declining Species	Scientific Name	No. Units	Atlas 1 RR	Atlas 2 RR	% Change	p value
Emu	*Dromaius novaehollandiae*	206	0.1318	0.0808	-38.7	<0.001
Freckled Duck	*Stictonetta naevosa*	52	0.01902	0.01259	-33.8	0.042
Black-browed Albatross	*Thalassarche melanophrys*	28	0.02337	0.01258	-46.2	0.019
Eastern Reef Egret	*Egretta sacra*	24	0.03785	0.02065	-45.4	0.025
Wedge-tailed Eagle	*Aquila audax*	284	0.1548	0.1315	-15.0	0.001
Latham's Snipe	*Gallinago hardwickii*	96	0.02244	0.01714	-23.6	0.044
Grey-tailed Tattler	*Heteroscelus brevipes*	30	0.03641	0.02124	-41.7	0.032
Red Knot	*Calidris canutus*	24	0.02108	0.00802	-62.0	<0.001
Sharp-tailed Sandpiper	*Calidris acuminata*	108	0.0266	0.01837	-31.0	0.008
Curlew Sandpiper	*Calidris ferruginea*	52	0.01796	0.00971	-45.9	<0.001
Bush Stone-curlew	*Burhinus grallarius*	28	0.02048	0.00754	-63.2	0.007
Pacific Golden Plover	*Pluvialis fulva*	40	0.02177	0.01217	-44.1	0.01
Australian Pratincole	*Stiltia isabella*	62	0.04043	0.01732	-57.2	<0.001
Arctic Jaeger	*Stercorarius parasiticus*	24	0.03063	0.01156	-62.3	0.008
Peaceful Dove	*Geopelia striata*	256	0.1219	0.1059	-13.2	0.008
Gang-gang Cockatoo	*Callocephalon fimbriatum*	62	0.08644	0.04871	-43.6	<0.001
Major Mitchell's Cockatoo	*Cacatua leadbeateri*	112	0.10363	0.07185	-30.7	0.005
Swift Parrot	*Lathamus discolor*	22	0.004167	0.010133	143.2	0.023
Brush Cuckoo	*Cacomantis variolosus*	96	0.02302	0.01771	-23.1	0.023
Southern Boobook	*Ninox novaeseelandiae*	190	0.02795	0.02095	-25.0	0.001
Barn Owl	*Tyto alba*	100	0.02472	0.00964	-61.0	<0.001
White-throated Needletail	*Hirundapus caudacutus*	126	0.0302	0.0157	-48.0	<0.001
Fork-tailed Swift	*Apus pacificus*	58	0.012791	0.006477	-49.4	<0.001
Laughing Kookaburra ▼	*Dacelo novaeguineae*	250	0.3116	0.288	-7.6	0.035
Yellow-rumped Thornbill ▼	*Acanthiza chrysorrhoa*	282	0.2256	0.1702	-24.6	<0.001
Striated Thornbill	*Acanthiza lineata*	156	0.07831	0.06503	-17.0	0.022
Painted Honeyeater	*Grantiella picta*	60	0.02185	0.01326	-39.3	0.009
Orange Chat	*Ephthianura aurifrons*	96	0.07367	0.04923	-33.2	0.002
Flame Robin	*Petroica phoenicea*	116	0.0759	0.03357	-55.8	<0.001
Hooded Robin	*Melanodryas cucullata*	208	0.06485	0.03811	-41.2	<0.001
Spotted Quail-thrush	*Cinclosoma punctatum*	94	0.02444	0.01772	-27.5	0.012
Crested Shrike-tit	*Falcunculus frontatus*	174	0.05629	0.04613	-18.0	0.003
Satin Flycatcher	*Myiagra cyanoleuca*	84	0.02368	0.0147	-37.9	0.002
White-winged Triller	*Lalage sueurii*	260	0.09615	0.05761	-40.1	<0.001
Grey Currawong	*Strepera versicolor*	72	0.03832	0.02623	-31.5	0.002
White-winged Chough	*Corcorax melanorhamphos*	262	0.1651	0.1299	-21.4	<0.001
Skylark	*Alauda arvensis*	58	0.03717	0.02459	-33.8	0.006
Richard's Pipit ▼	*Anthus novaeseelandiae*	284	0.309	0.138	-55.3	<0.001
House Sparrow ▼	*Passer domesticus*	252	0.1832	0.1112	-39.3	<0.001
Double-barred Finch	*Taeniopygia bichenovii*	178	0.06428	0.05163	-19.7	0.004
Red-browed Finch	*Neochmia temporalis*	148	0.1852	0.1597	-13.7	0.014
European Goldfinch ▼	*Carduelis carduelis*	108	0.13152	0.04673	-64.5	<0.001
Rufous Songlark ▼	*Cinclorhamphus mathewsi*	256	0.11035	0.08883	-19.5	0.001
Brown Songlark	*Cinclorhamphus cruralis*	222	0.06307	0.03474	-44.9	<0.001

Table 5. Bird species showing no variation between NSW IBRA bioregions and, across the whole state, were recorded more frequently in *Atlas 2* compared with *Atlas 1* (69 species). For an explanation of codes, see the caption for Table 1.

Increasing species	Scientific Name	No. Units	Atlas 1 RR	Atlas 2 RR	% Change	p value
Brown Quail	*Coturnix ypsilophora*	128	0.00911	0.0224	145.8	<0.001
Magpie Goose	*Anseranas semipalmata*	18	0.00452	0.03559	686.6	<0.001
Australian Shelduck	*Tadorna tadornoides*	108	0.02695	0.03531	31.0	0.029
Chestnut Teal	*Anas castanea*	134	0.03661	0.06929	89.3	<0.001
Intermediate Egret	*Ardea intermedia*	126	0.01925	0.02911	51.2	0.002
Cattle Egret	*Ardea ibis*	100	0.02698	0.03578	32.6	0.001
Striated Heron	*Butorides striatus*	32	0.02372	0.039	64.4	0.001
Osprey	*Pandion haliaetus*	30	0.01233	0.03773	206.1	<0.001
Swamp Harrier	*Circus approximans*	138	0.02001	0.0257	28.4	0.025
Collared Sparrowhawk	*Accipiter cirrhocephalus*	182	0.02218	0.02897	30.6	0.004
Australian Hobby	*Falco longipennis*	236	0.02805	0.03343	19.2	0.017
Peregrine Falcon	*Falco peregrinus*	154	0.01546	0.02067	33.7	0.004
Buff-banded Rail	*Gallirallus philippensis*	54	0.00604	0.01656	174.3	<0.001
Spotless Crake	*Porzana tabuensis*	34	0.005674	0.010041	77.0	0.038
Marsh Sandpiper	*Tringa stagnatilis*	50	0.00884	0.01959	121.6	0.006
Comb-crested Jacana	*Irediparra gallinacea*	16	0.01569	0.03073	95.9	0.051
Caspian Tern	*Sterna caspia*	66	0.01651	0.02579	56.2	0.015
White-headed Pigeon	*Columba leucomela*	38	0.00696	0.02822	305.5	<0.001
Spotted Turtle-Dove	*Streptopelia chinensis*	68	0.03548	0.07837	120.9	<0.001
Common Bronzewing	*Phaps chalcoptera*	256	0.05515	0.08171	48.1	<0.001
Crested Pigeon ▼	*Ocyphaps lophotes*	274	0.2599	0.3409	31.2	<0.001
Yellow-tailed Black-Cockatoo	*Calyptorhynchus funereus*	106	0.03672	0.0629	71.3	<0.001
Long-billed Corella	*Cacatua tenuirostris*	34	0.0061	0.01822	198.8	<0.001
Rainbow Lorikeet	*Trichoglossus haematodus*	80	0.02389	0.09533	299.0	<0.001
Scaly-breasted Lorikeet ▲	*Trichoglossus chlorolepidotus*	50	0.01066	0.02207	107.0	0.008
Australian King Parrot ▼	*Alisterus scapularis*	126	0.04958	0.06995	41.1	<0.001
Red-winged Parrot	*Aprosmictus erythropterus*	86	0.06132	0.10127	65.1	<0.001
Superb Parrot	*Polytelis swainsonii*	70	0.02605	0.04747	82.3	0.001
Crimson Rosella	*Platycercus elegans*	172	0.1938	0.2373	22.4	0.004
Fan-tailed Cuckoo	*Cacomantis flabelliformis*	210	0.05495	0.07144	30.0	<0.001
Common Koel	*Eudynamys scolopacea*	70	0.01357	0.02385	75.8	0.001
Pheasant Coucal	*Centropus phasianinus*	36	0.00793	0.01815	129.0	0.002
Australian Owlet-nightjar	*Aegotheles cristatus*	168	0.01912	0.02337	22.2	0.036
Noisy Pitta	*Pitta versicolor*	22	0.0072	0.01326	84.3	0.038
Variegated Fairy-wren	*Malurus lamberti*	22	0.003363	0.016047	377.1	<0.001
Spotted Pardalote ▼	*Pardalotus punctatus*	224	0.0989	0.1411	42.6	<0.001
Striated Pardalote	*Pardalotus striatus*	286	0.1902	0.2233	17.4	<0.001
White-browed Scrubwren	*Sericornis frontalis*	134	0.113	0.1318	16.6	0.053
Brown Gerygone	*Gerygone mouki*	62	0.04294	0.0622	44.8	0.019
White-throated Gerygone	*Gerygone olivacea*	136	0.05878	0.07339	24.9	0.001
Brown Thornbill	*Acanthiza pusilla*	146	0.0968	0.1293	33.6	<0.001
Yellow Thornbill ▼	*Acanthiza nana*	244	0.1139	0.13	14.1	0.017
Little Wattlebird ▲	*Anthochaera lunulata*	58	0.03845	0.07501	95.1	0.004
Red Wattlebird	*Anthochaera carunculata*	170	0.0874	0.1693	93.6	<0.001
Regent Honeyeater	*Xanthomyza phrygia*	38	0.00797	0.01817	128.1	0.03

APPENDIX 1

Increasing species	Scientific Name	No. Units	Atlas 1 RR	Atlas 2 RR	% Change	p value
Noisy Miner	*Manorina melanocephala*	226	0.2616	0.3005	14.9	0.003
Yellow-faced Honeyeater ▼	*Lichenostomus chrysops*	148	0.1401	0.1797	28.2	<0.001
White-fronted Honeyeater	*Phylidonyris albifrons*	76	0.03461	0.07007	102.5	<0.001
Black Honeyeater	*Certhionyx niger*	68	0.02665	0.04047	51.9	0.032
Pied Honeyeater	*Certhionyx variegatus*	32	0.0326	0.06666	104.5	0.004
Scarlet Honeyeater	*Myzomela sanguinolenta*	78	0.02616	0.03729	42.5	0.003
Eastern Yellow Robin	*Eopsaltria australis*	186	0.1327	0.1511	13.9	0.024
White-browed Babbler	*Pomatostomus superciliosus*	166	0.05497	0.07143	29.9	0.006
Eastern Whipbird	*Psophodes olivaceus*	80	0.06529	0.11214	71.8	<0.001
Gilbert's Whistler	*Pachycephala inornata*	38	0.03152	0.05242	66.3	0.033
Golden Whistler	*Pachycephala pectoralis*	192	0.0857	0.0987	15.2	0.017
Spangled Drongo	*Dicrurus bracteatus*	36	0.02696	0.0383	42.1	0.016
Olive-backed Oriole	*Oriolus sagittatus*	194	0.04717	0.05862	24.3	<0.001
Figbird	*Sphecotheres viridis*	42	0.00482	0.01657	243.7	<0.001
Grey Butcherbird ▼	*Cracticus torquatus*	276	0.1675	0.2221	32.6	<0.001
Pied Currawong	*Strepera graculina*	182	0.2091	0.2324	11.2	0.012
Little Crow	*Corvus bennetti*	114	0.07127	0.09462	32.8	0.028
Torresian Crow ▲	*Corvus orru*	50	0.03371	0.09684	187.3	<0.001
Green Catbird	*Ailuroedus crassirostris*	34	0.01875	0.03048	62.6	0.022
Satin Bowerbird	*Ptilonorhynchus violaceus*	96	0.03103	0.04583	47.7	0.002
Tawny Grassbird	*Megalurus timoriensis*	34	0.02065	0.03525	70.7	0.042
Little Grassbird	*Megalurus gramineus*	162	0.02126	0.02954	38.9	0.002
Silvereye	*Zosterops lateralis*	198	0.1178	0.138	17.1	0.012
Common Myna	*Acridotheres tristis*	72	0.02194	0.05271	140.2	<0.001

Table 6. Bird species showing no variation between NSW IBRA bioregions and, across the whole state, showed no change in reporting rate between *Atlas 2* and *Atlas 1* (103 species). For an explanation of codes, see the caption for Table 1.

Species showing no change	Scientific Name	No. Units	Atlas 1 RR	Atlas 2 RR	% Change	p value
Australian Brush-turkey	*Alectura lathami*	32	0.02034	0.01656	-18.6	0.101
Musk Duck	*Biziura lobata*	150	0.03374	0.03802	12.7	0.275
Mallard	*Anas platyrhynchos*	50	0.0149	0.0181	21.4	0.245
Great Crested Grebe	*Podiceps cristatus*	92	0.02418	0.02772	14.6	0.472
Little Penguin	*Eudyptula minor*	18	0.02826	0.02536	-10.3	0.758
Sooty Shearwater	*Puffinus griseus*	16	0.02648	0.01421	-46.3	0.172
Shy Albatross	*Thalassarche cauta*	16	0.01738	0.01781	2.5	0.963
Yellow-nosed Albatross	*Thalassarche chlororhynchos*	20	0.02147	0.01364	-36.5	0.19
Australasian Gannet	*Morus serrator*	32	0.12965	0.07002	-46.0	0.087
Little Egret	*Egretta garzetta*	98	0.02466	0.02895	17.4	0.261
Australasian Bittern	*Botaurus poiciloptilus*	50	0.01528	0.01146	-25.1	0.229
Black-necked Stork	*Ephippiorhynchus asiaticus*	36	0.01724	0.014	-18.8	0.369
Pacific Baza	*Aviceda subcristata*	34	0.01024	0.01616	57.9	0.153
Square-tailed Kite	*Lophoictinia isura*	40	0.01118	0.01574	40.8	0.219
Black Kite	*Milvus migrans*	176	0.05659	0.06303	11.4	0.286
Brahminy Kite ▼	*Haliastur indus*	16	0.01812	0.02854	57.5	0.099
Grey Goshawk	*Accipiter novaehollandiae*	58	0.0099	0.01345	35.9	0.091
Australian Spotted Crake	*Porzana fluminea*	54	0.01364	0.01105	-19.0	0.31
Black-tailed Native-hen	*Gallinula ventralis*	128	0.035	0.04151	18.6	0.137

APPENDIX 1

Species showing no change	Scientific Name	No. Units	Atlas 1 RR	Atlas 2 RR	% Change	p value
Little Button-quail	*Turnix velox*	50	0.02753	0.02863	4.0	0.832
Black-tailed Godwit	*Limosa limosa*	26	0.008029	0.009003	12.1	0.739
Bar-tailed Godwit	*Limosa lapponica*	36	0.0566	0.0497	-12.2	0.485
Eastern Curlew	*Numenius madagascariensis*	36	0.06513	0.05588	-14.2	0.457
Common Greenshank	*Tringa nebularia*	94	0.02351	0.02425	3.2	0.829
Common Sandpiper	*Actitis hypoleucos*	30	0.007668	0.006732	-12.2	0.584
Red-necked Stint	*Calidris ruficollis*	62	0.01407	0.00968	-31.2	0.13
Red-necked Avocet	*Recurvirostra novaehollandiae*	84	0.02988	0.04159	39.2	0.08
Red-capped Plover	*Charadrius ruficapillus*	100	0.02714	0.02714	0.0	0.999
Double-banded Plover	*Charadrius bicinctus*	46	0.01224	0.00913	-25.4	0.315
Silver Gull	*Larus novaehollandiae*	176	0.08652	0.08119	-6.2	0.442
Gull-billed Tern*	*Sterna nilotica*	72	0.01474	0.0122	-17.2	0.288
White-fronted Tern	*Sterna striata*	22	0.01391	0.01297	-6.7	0.862
Whiskered Tern	*Chlidonias hybridus*	108	0.02881	0.0284	-1.4	0.905
Brown Cuckoo-Dove	*Macropygia amboinensis*	44	0.06223	0.0539	-13.4	0.224
Emerald Dove	*Chalcophaps indica*	30	0.02066	0.0162	-21.6	0.246
Brush Bronzewing	*Phaps elegans*	36	0.00848	0.008051	-5.1	0.867
Wonga Pigeon	*Leucosarcia melanoleuca*	82	0.02662	0.03414	28.3	0.115
Wompoo Fruit-Dove	*Ptilinopus magnificus*	22	0.01343	0.02369	76.5	0.059
Topknot Pigeon	*Lopholaimus antarcticus*	46	0.01883	0.02012	6.8	0.773
Red-tailed Black-Cockatoo	*Calyptorhynchus banksii*	32	0.07012	0.04601	-34.4	0.149
Glossy Black-Cockatoo	*Calyptorhynchus lathami*	88	0.01789	0.0209	16.8	0.236
Little Lorikeet	*Glossopsitta pusilla*	108	0.05894	0.06601	12.0	0.389
Pale-headed Rosella	*Platycercus adscitus*	44	0.03245	0.036	10.9	0.609
Australian Ringneck	*Barnardius zonarius*	176	0.1046	0.1134	8.4	0.35
Turquoise Parrot	*Neophema pulchella*	74	0.01801	0.02047	13.7	0.362
Black-eared Cuckoo	*Chrysococcyx osculans*	86	0.0238	0.02701	13.5	0.413
Shining Bronze-Cuckoo	*Chrysococcyx lucidus*	146	0.02799	0.03286	17.4	0.061
Powerful Owl	*Ninox strenua*	26	0.01401	0.01191	-15.0	0.535
Tawny Frogmouth	*Podargus strigoides*	176	0.02579	0.02211	-14.3	0.092
Azure Kingfisher	*Alcedo azurea*	94	0.02456	0.02301	-6.3	0.644
Forest Kingfisher	*Todirhamphus macleayii*	18	0.009926	0.007383	-25.6	0.148
Superb Lyrebird	*Menura novaehollandiae*	88	0.05136	0.04593	-10.6	0.421
White-browed Treecreeper	*Climacteris affinis*	40	0.05392	0.05798	7.5	0.748
Splendid Fairy-wren	*Malurus splendens*	80	0.04271	0.0521	22.0	0.085
Red-backed Fairy-wren	*Malurus melanocephalus*	20	0.03587	0.04837	34.9	0.086
Southern Emu-wren	*Stipiturus malachurus*	32	0.01904	0.01659	-12.8	0.537
Pilotbird	*Pycnoptilus floccosus*	32	0.01753	0.01378	-21.4	0.418
Rockwarbler	*Origma solitaria*	32	0.03077	0.02287	-25.7	0.276
Yellow-throated Scrubwren	*Sericornis citreogularis*	38	0.02681	0.0213	-20.6	0.099
Large-billed Scrubwren	*Sericornis magnirostris*	50	0.03204	0.02856	-10.9	0.315
Chestnut-rumped Heathwren	*Hylacola pyrrhopygia*	58	0.01367	0.01095	-19.9	0.146
Shy Heathwren	*Hylacola cauta*	18	0.02736	0.05354	95.7	0.096
Speckled Warbler	*Chthonicola sagittata*	130	0.0484	0.05027	3.9	0.733
Mangrove Gerygone	*Gerygone levigaster*	18	0.03224	0.0364	12.9	0.552
Western Gerygone ▼	*Gerygone fusca*	166	0.05307	0.05794	9.2	0.349
Inland Thornbill	*Acanthiza albiventris*	130	0.0437	0.04827	10.5	0.302
Buff-rumped Thornbill	*Acanthiza reguloides*	180	0.05598	0.05831	4.2	0.622

APPENDIX 1

Species showing no change	Scientific Name	No. Units	Atlas 1 RR	Atlas 2 RR	% Change	p value
Little Friarbird	*Philemon citreogularis*	198	0.06466	0.06739	4.2	0.543
Bell Miner	*Manorina melanophrys*	54	0.03413	0.04238	24.2	0.371
White-eared Honeyeater ▲	*Lichenostomus leucotis*	170	0.10181	0.09524	-6.4	0.415
Yellow-tufted Honeyeater	*Lichenostomus melanops*	94	0.03549	0.03169	-10.7	0.419
Yellow-plumed Honeyeater	*Lichenostomus ornatus*	62	0.06389	0.05612	-12.2	0.5
Grey-fronted Honeyeater	*Lichenostomus plumulus*	30	0.02872	0.02961	3.1	0.88
Fuscous Honeyeater	*Lichenostomus fuscus*	122	0.05764	0.05958	3.4	0.705
Black-chinned Honeyeater	*Melithreptus gularis*	84	0.02096	0.02271	8.3	0.475
Brown-headed Honeyeater	*Melithreptus brevirostris*	212	0.07581	0.06729	-11.2	0.08
White-naped Honeyeater	*Melithreptus lunatus*	134	0.06042	0.05228	-13.5	0.076
Brown Honeyeater ▼	*Lichmera indistincta*	74	0.04893	0.05833	19.2	0.223
Crescent Honeyeater	*Phylidonyris pyrrhoptera*	40	0.02106	0.02373	12.7	0.532
New Holland Honeyeater	*Phylidonyris novaehollandiae*	84	0.06097	0.05601	-8.1	0.319
White-cheeked Honeyeater	*Phylidonyris nigra*	46	0.05992	0.05373	-10.3	0.536
Tawny-crowned Honeyeater	*Phylidonyris melanops*	24	0.01149	0.02055	78.9	0.162
Eastern Spinebill	*Acanthorhynchus tenuirostris*	126	0.1086	0.1259	15.9	0.075
Pale-yellow Robin	*Tregellasia capito*	20	0.03678	0.02656	-27.8	0.252
Logrunner	*Orthonyx temminckii*	28	0.0298	0.02346	-21.3	0.177
Grey-crowned Babbler	*Pomatostomus temporalis*	172	0.06596	0.07073	7.2	0.388
Chirruping Wedgebill	*Psophodes occidentalis*	42	0.1545	0.1667	7.8	0.682
Chestnut-backed Quail-thrush	*Cinclosoma castanotus*	18	0.03614	0.0672	85.9	0.122
Crested Bellbird	*Oreoica gutturalis*	126	0.07881	0.08799	11.6	0.308
Rufous Whistler ▼	*Pachycephala rufiventris*	278	0.2077	0.196	-5.6	0.14
Black-faced Monarch	*Monarcha melanopsis*	60	0.03139	0.03062	-2.5	0.875
Leaden Flycatcher	*Myiagra rubecula*	136	0.03836	0.03892	1.5	0.868
Rufous Fantail	*Rhipidura rufifrons*	90	0.02498	0.02632	5.4	0.656
Black-faced Cuckoo-shrike ▼	*Coracina novaehollandiae*	288	0.271	0.2569	-5.2	0.098
White-bellied Cuckoo-shrike	*Coracina papuensis*	114	0.02372	0.02389	0.7	0.955
Cicadabird	*Coracina tenuirostris*	94	0.01722	0.02139	24.2	0.078
Australian Magpie ▼	*Gymnorhina tibicen*	286	0.6412	0.6432	0.3	0.864
Paradise Riflebird	*Ptiloris paradiseus*	20	0.007995	0.01105	38.2	0.246
Forest Raven	*Corvus tasmanicus*	24	0.04107	0.05383	31.1	0.373
Spotted Bowerbird	*Chlamydera maculata*	82	0.04164	0.05132	23.2	0.163
Chestnut-breasted Mannikin	*Lonchura castaneothorax*	32	0.02575	0.02095	-18.6	0.324
Red-whiskered Bulbul	*Pycnonotus jocosus*	16	0.03078	0.05061	64.4	0.072
Golden-headed Cisticola	*Cisticola exilis*	124	0.03336	0.03625	8.7	0.481

APPENDIX 2

Appendix 2: Analysis of change in reporting rate between *Atlas 1* and *Atlas 2*

Analysis of proportions data

As the data were proportions, i.e. the number of surveys in which the species was recorded as a proportion of the total number of surveys for each 1° grid, it was tempting to treat the data as binomial and to use standard methods for the analysis of binomial data. Before proceeding with the analysis, the conditions that apply for data to be approximated by a binomial distribution were assessed.

Proportions data will follow a binomial distribution under the following circumstances:

1. The outcome consists of a finite, known number of identical surveys.
2. Each survey can result in only one of two possible outcomes – a sighting or no sighting.
3. The probability of a sighting in each survey (represented as p) is constant.
4. The surveys are independent and bird sightings between surveys are independent.

These conditions were approximately satisfied, so the appropriate statistical analysis for comparing reporting rates for a given grid was a comparison of proportions *p1* and *p2* (*Atlas 1* and *Atlas 2*), with variance of each *p* given by the formula for binomial variance as $p\ (1-p)/n$. These ideas easily generalize to the situation where we have many grids to compare. In its general form this type of analysis is often referred to as logistic regression.

It is clear from knowledge of the atlas data collection procedures that conditions 3 and 4 may not apply. For example, response probabilities were likely to differ between search method, observers and habitat and in many instances, the same observer often carried out multiple surveys at the same location. Both the lack of independence and heterogeneity among the reporting rate probabilities (failure of assumptions 4 and 3, respectively) will result in our reporting rate data having variance greater than that on the assumption of binomial variability. This is often referred to as over-dispersion and was appropriately taken account of using methods described by Collett (1991).

A further important feature of the data is that it was grouped at the 1° grid level with the grids being matched across atlases. Thus the true structure of the data is multi-level, with the two levels being grid and observation within grid, for *Atlas 1* and *Atlas 2*. This feature was accounted for in our analysis by fitting a random effect for grid, thus giving two components of variance – grid and observation within grid.

It is also likely that reporting rates of grids were spatially correlated. However as we were principally concerned with making inferences about change, which occurs within grids, any such spatial correlation should have little effect on our inferences. This assumption was checked for a number of species and was found to be reasonable. We have therefore chosen not to explicitly model spatial dependence among grids for the species analysed.

Another important feature of atlas data is that variation of both survey effort and observed reporting rates was high. We know for the binomial distribution that the variance of reporting rates depends on survey effort (the number of surveys). Our analysis also found that, for some species, the mean reporting rate also depended on survey effort. A possible explanation for this unusual result is related to the spatial distribution of the species, and the spatial distribution and behaviour of observers. For example, the Emu, a semi-arid species, showed high reporting rates where survey effort was generally low, and low reporting rates where survey effort was high. Thus we statistically adjusted for possible differences in survey effort between atlases for each grid.

Model formulation

After a detailed examination of the many options available, we chose an approach that best captures the non-standard features of the data. For a given species, the probability (*p*) of a bird being sighted in a survey, depends on atlas type (*Atlas 1* or *Atlas 2*), IBRA bioregion and possibly an interaction between atlas type and IBRA bioregion and survey effort. One-degree grids were classified by IBRA bioregion to assess spatial consistency of change at this scale. As it does not make sense to have proportions outside the bounds 0 and 1, observed proportions were transformed by the empirical logit, i.e. Log {(# sightings + 0.5) /(# surveys – # sightings + 0.5)}. Fitted values are antilogits and can never be <0 or >1. Thus our initial mean model took the form: Expected value [logit (*p*)] = Constant + atlas type (fixed effect) + IBRA bioregion (fixed effect) + an interaction between atlas type and IBRA bioregion + survey effort (fixed effect). Variance components were estimated by restricted maximum likelihood in this general linear mixed model, and parameters for fixed effects were estimated by weighted least square. We used extrinsic weights as the inverse of the estimated variance of the empirical logit, (var [logit {*p*}] = (#surveys + 1) / [(#sightings + 0.5) (#surveys – #sightings + 0.5)]) to account for the fact that the variance also depended on survey effort. This formula could have been further adjusted for lack of independence but this was already partly accounted for by the fact that we used the empirical transformation of *p* and treated these data as continuous. The adjusted reporting rates (adjusted for survey effort), can be interpreted as an estimate of the probability of sighting for a single randomly chosen survey in both atlases.

The distributional properties of the model, in particular the variance function, and points having excessive influence on the fit, were studied by examining appropriate diagnostic plots – residuals *vs* fitted values, residuals against normal quantiles. In developing the model, evidence from these diagnostic plots was considered and changes to the data and/or model made. This could not be done individually for all species analysed. Inferences relating to the effects of interest; the overall change between atlases and the consistency of change between IBRA bioregions, was made by comparing change in deviance statistics, with critical values from a Chi-square distribution (with appropriate degrees of freedom).

Model summary

For each species a p-value (a measure of the strength of evidence against the no-change hypothesis) was presented for the overall differences in reporting rate between *Atlas 1* and *Atlas 2*, together with the adjusted reporting rates (adjusted for survey effort, Appendix 1). This p-value does not include the significance of the IBRA bioregional variation, which is dealt with separately (see below). The adjusted rates can be interpreted (approximately) as an estimate of the probability of sighting for a single randomly chosen survey in both atlases. If there was evidence, as measured by the change-in-deviance statistic, for lack of spatial consistency in the change the rates, then adjusted reporting rates were presented for each IBRA bioregion. The criteria for presenting and interpreting these spatial data was set at $p < 0.05$, for the relevant change in deviance statistic.

In most cases the log of survey method effect was a significant explanator, and so for simplicity, survey method effect was included in all models when determining whether they were significant or not. Where correcting for survey method effect reversed the result, making the result significant, it was considered a null result (no atlas type effect and no survey method effect).

Interpreting the models

It should be noted that there was a trade-off between bioregional variation and overall trends across the whole state. If the Atlas × IBRA bioregion interaction was significant and so included in model, the overall trend could change. For example, the Red-browed Treecreeper showed significant bioregional variation in the change between *Atlas 1* and *2*, but no overall decline (Appendix 1, Table 3, -31%, p = 0.335, Appendix 3 Figure 11). If the Atlas × IBRA bioregion interaction were to be excluded from the model, the result is a significant decline overall (-46%, p = 0.001).

Appendix 3: Distribution change maps for 18 species

(listed alphabetically)

Figures 1 to 18 show bird species with significant variation ($p<0.05$) in the change in reporting rates between *Atlas 1* and *Atlas 2.* IBRA bioregions are identified as showing a ≥ 20% increase in reporting rates in *Atlas 2* compared with *Atlas 1* (cross hatching), no change (i.e. < 20% change in reporting rate, grey) or ≥ 20% decrease in reporting rates in *Atlas 2* compared with *Atlas 1* (diagonal lines). IBRA bioregions with fewer than 40 surveys for both atlases (combined) were excluded, as were bioregions with an adjusted reporting rate of less than 0.03 in both *Atlas 1* and *Atlas 2.* For an explanation of codes for bioregions, see Table 1.

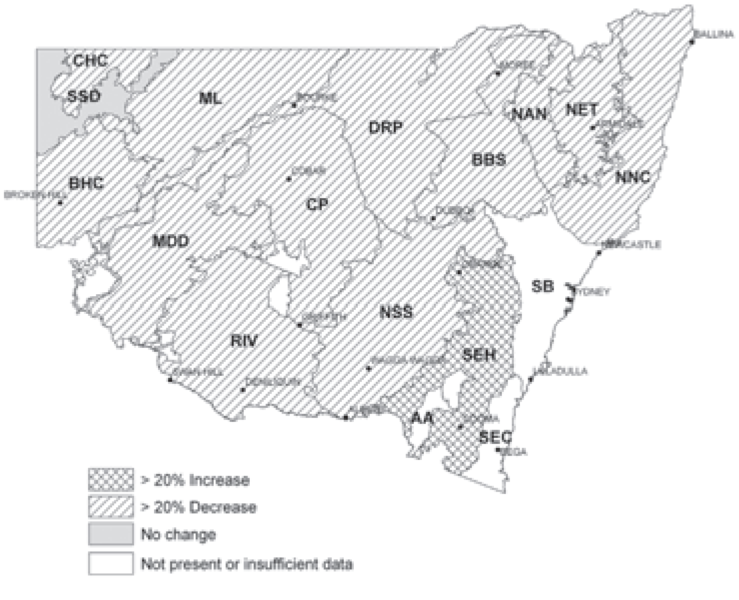

Figure 1. Black-faced Woodswallow

APPENDIX 3

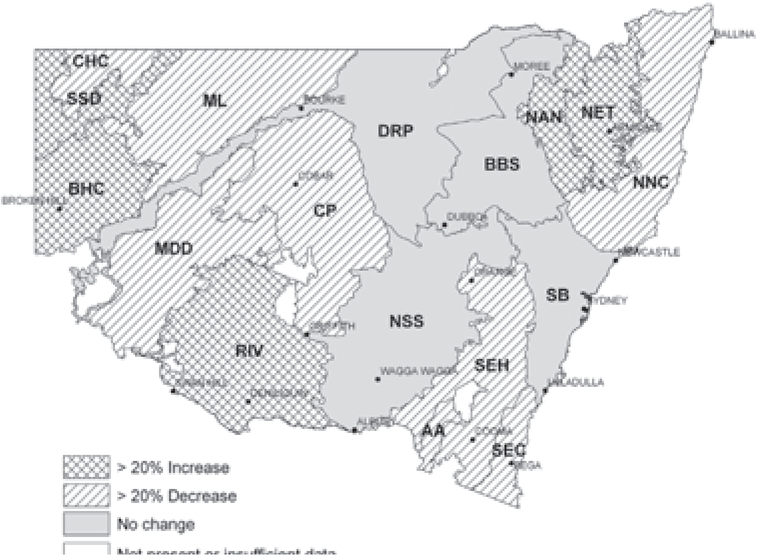

Figure 2. Brown Treecreeper

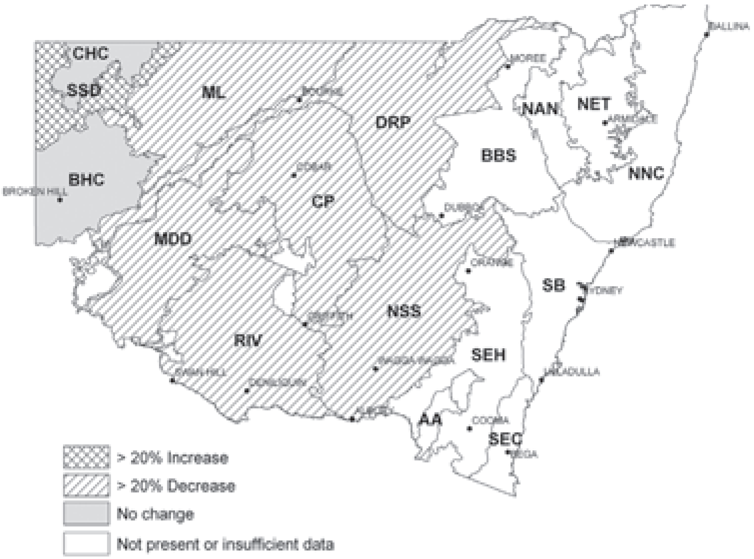

Figure 3. Chestnut-crowned Babbler

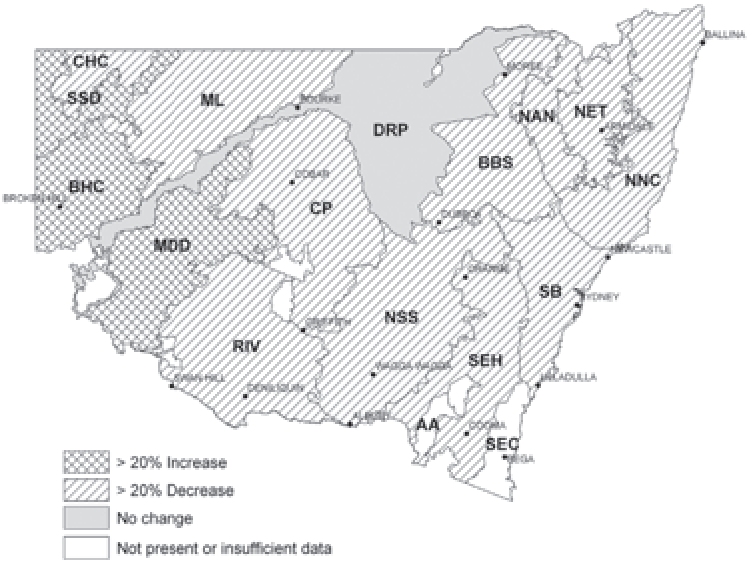

Figure 4. Cockatiel

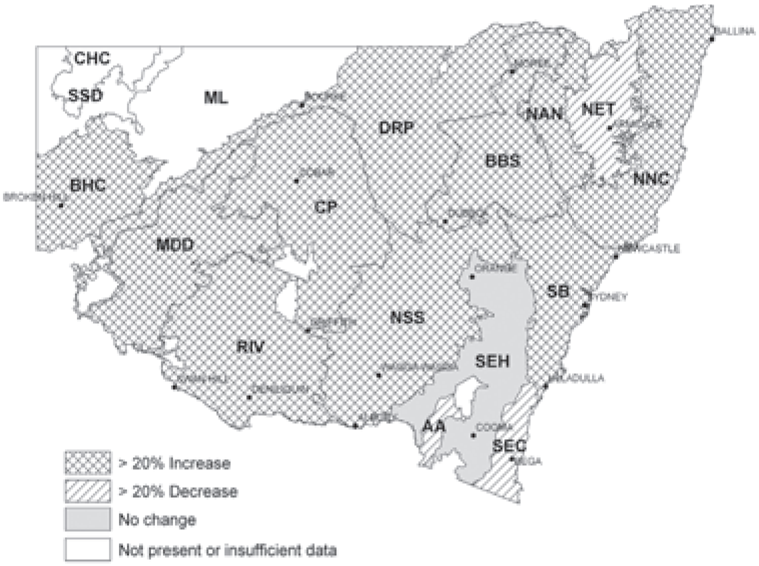

Figure 5. Common Blackbird

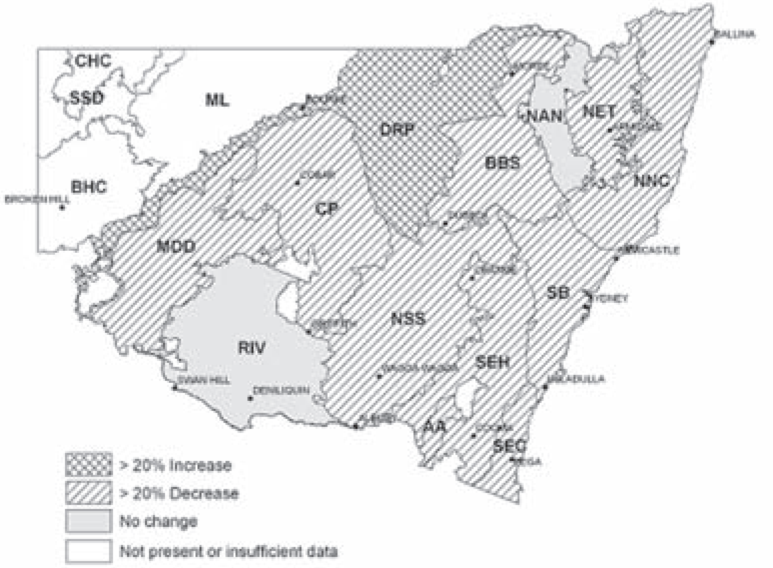

Figure 6. Diamond Firetail

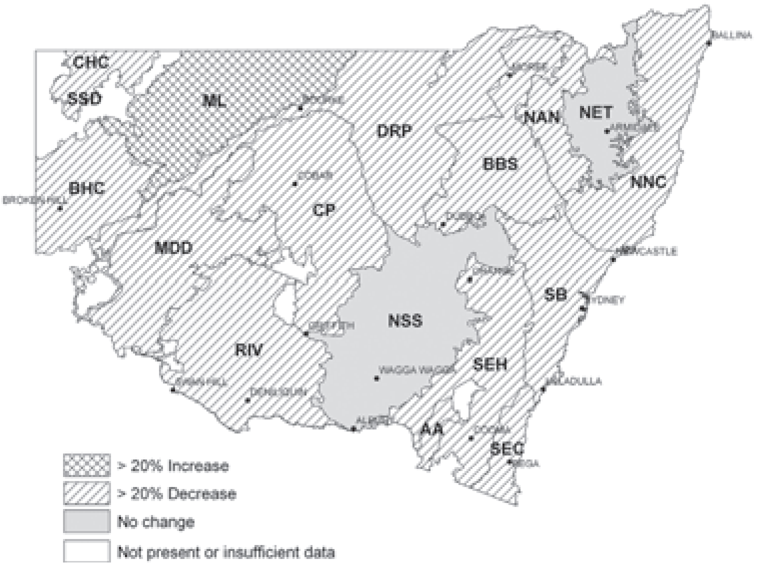

Figure 7. Dusky Woodswallow

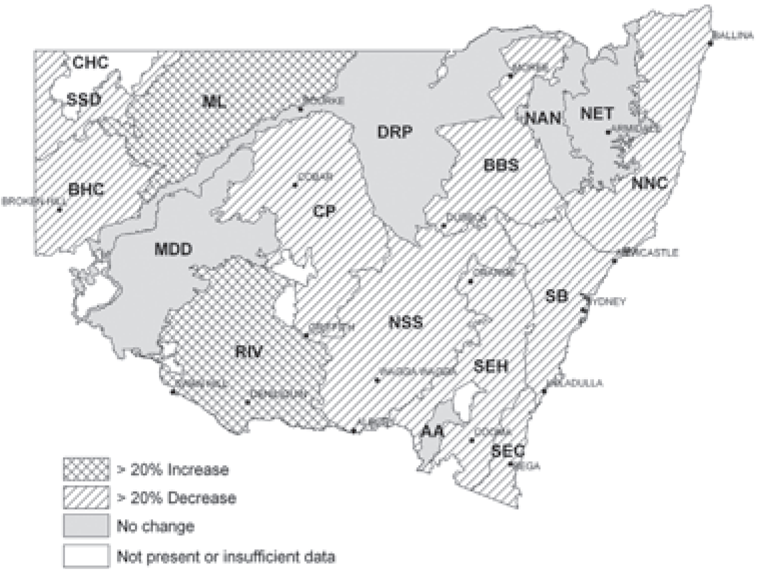

Figure 8. Jacky Winter

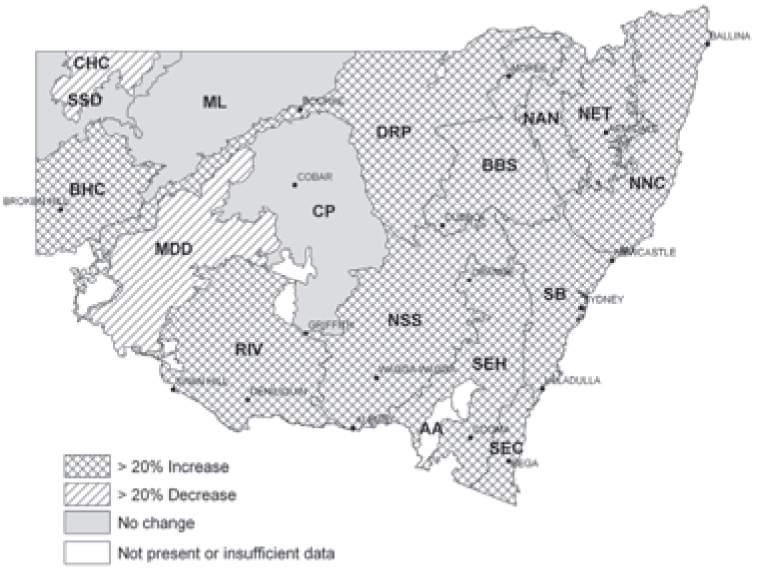

Figure 9. Little Corella

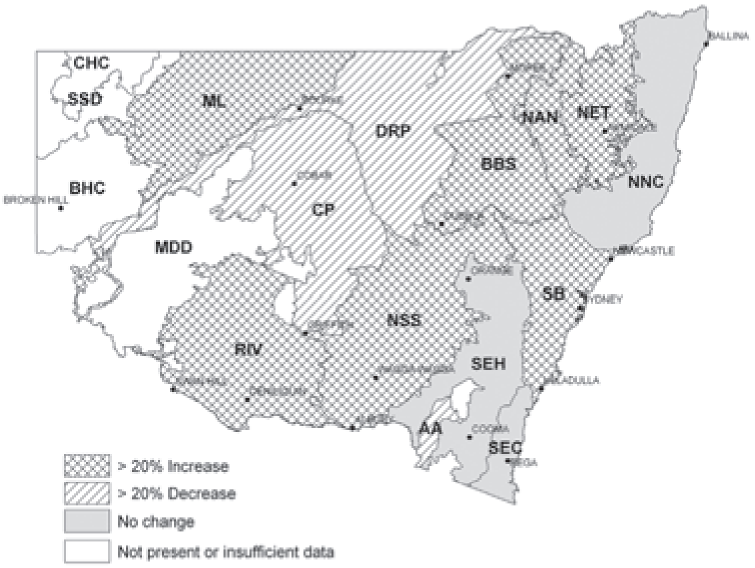

Figure 10. Noisy Friarbird

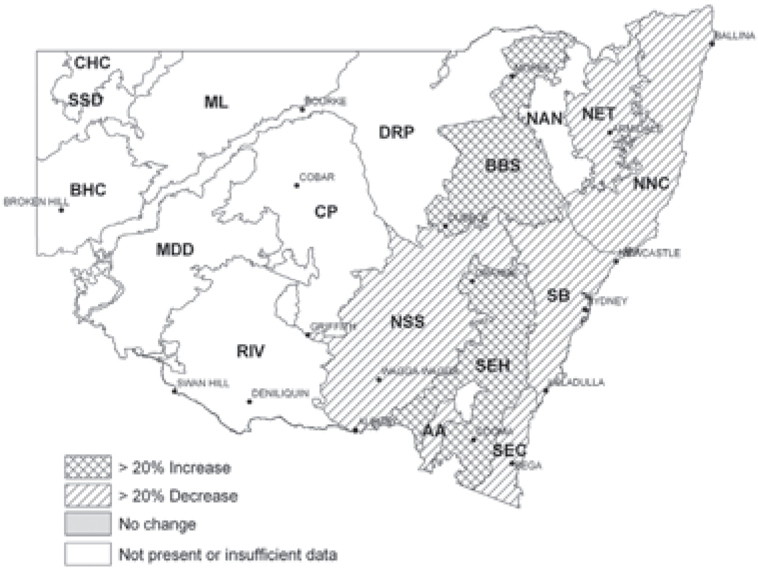

Figure 11. Red-browed Treecreeper

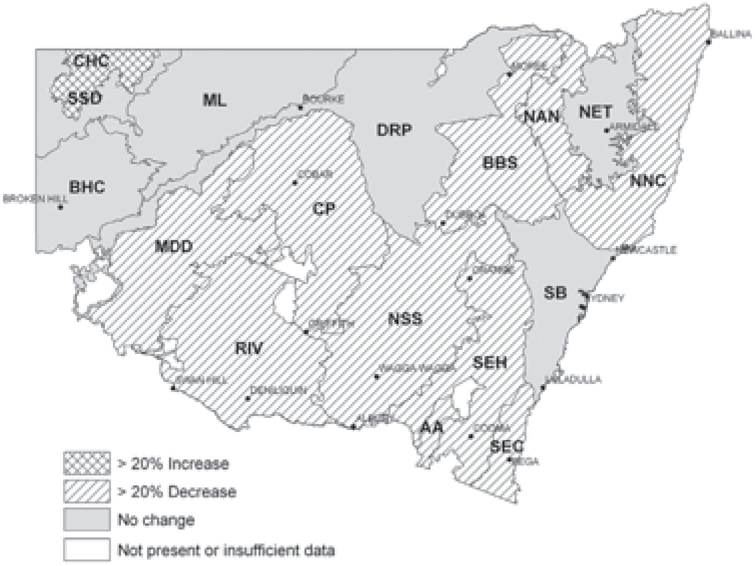

Figure 12. Restless Flycatcher

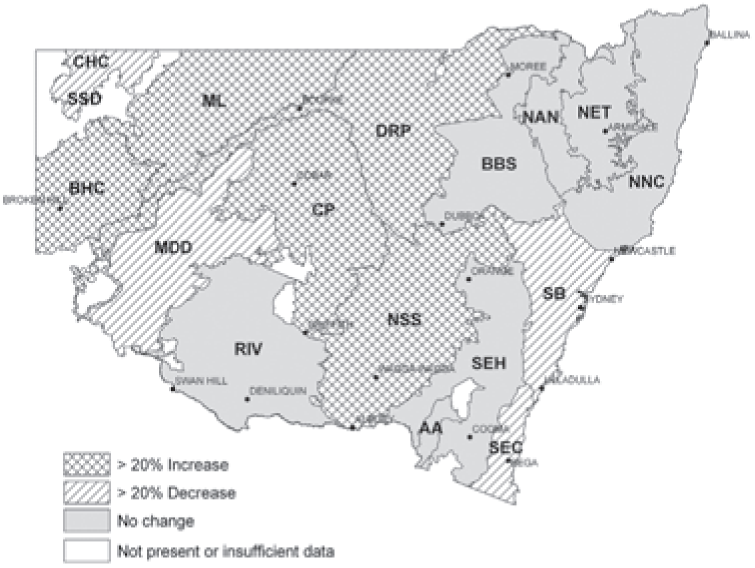

Figure 13. Sacred Kingfisher

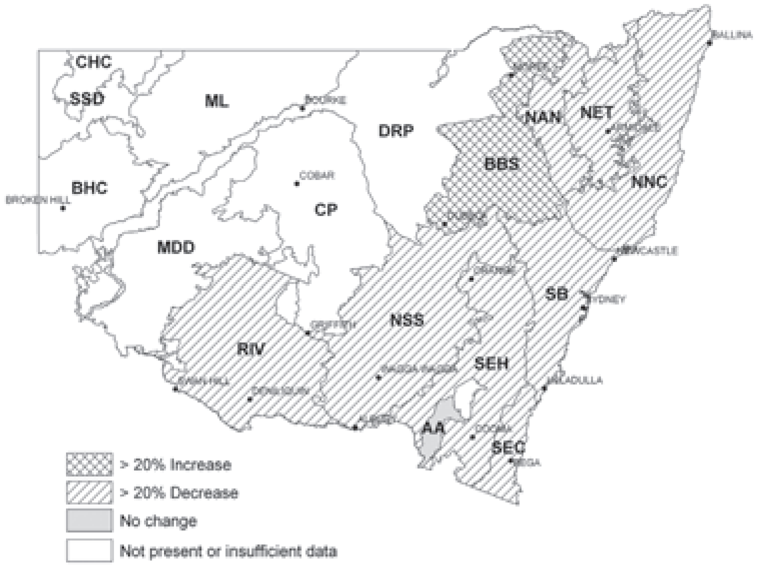

Figure 14. Scarlet Robin

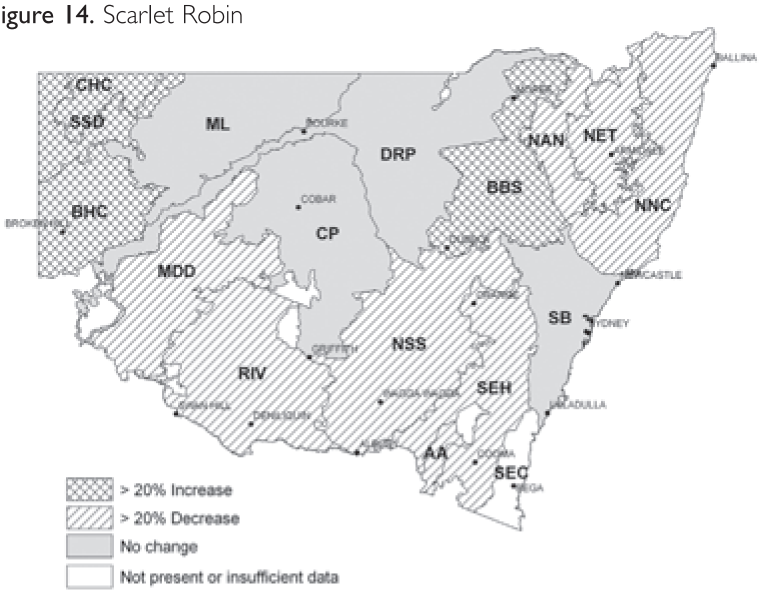

Figure 15. Southern Whiteface

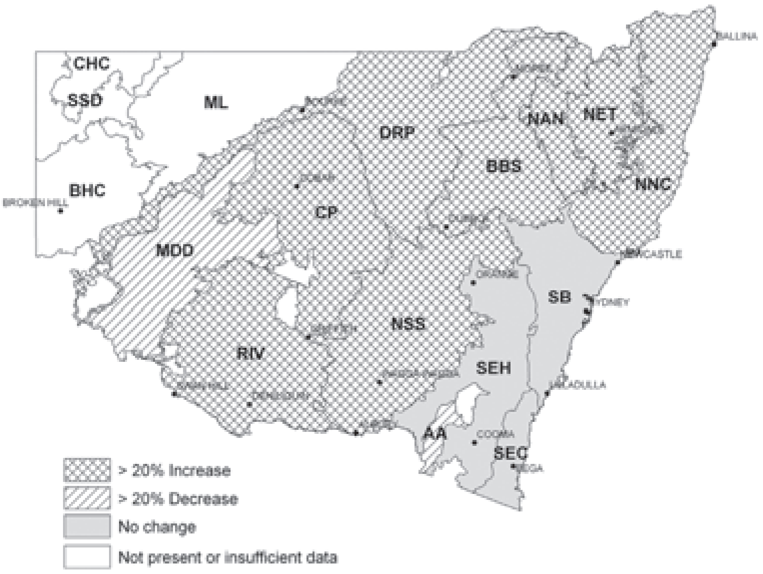

Figure 16. Superb Fairy-wren

APPENDIX 3

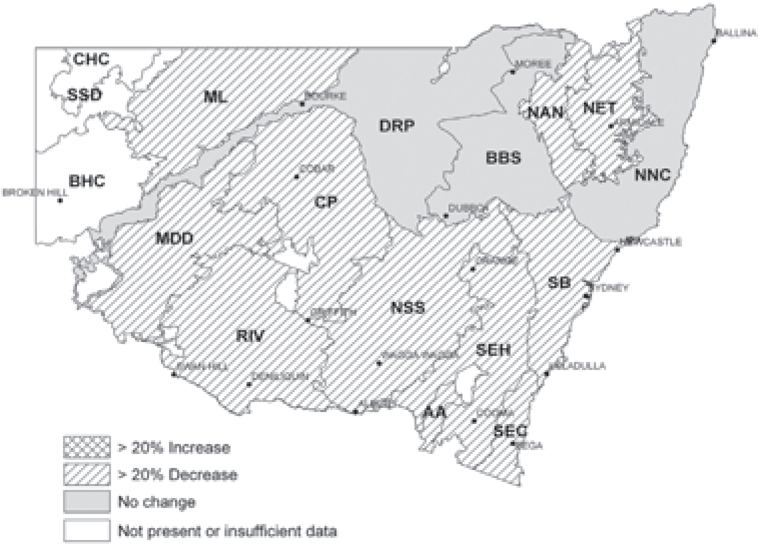

Figure 17. Varied Sittella

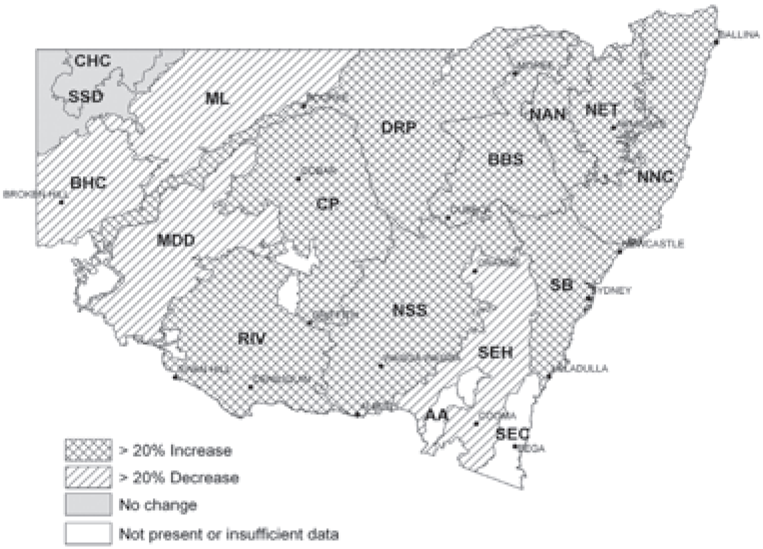

Figure 18. Zebra Finch

APPENDIX 4

Appendix 4: Spearman rank Correlation matrix for bird groups and environmental variables (n = 17 IBRA bioregions)

Table 1: Spearman rank correlation for the proportion of bird species found to be declining, increasing or showing no significant change in reporting rate across NSW, for each bioregion (n = 17 bioregions, RR = reporting rate, bird data in Table 2), against four environmental variables from the LWRA (data in Table 1).

	Landscape stress	% Native vegetation	% area impacted by grazing stock	Rainfall	% woodland species with >20% decrease in RR	% woodland species showing no change in RR	% woodland species showing no change in RR	No. Woodland species
Landscape stress	1							
% Native vegetation	-0.153	1						
% area impacted by grazing stock	0.052	-0.34	1					
Rainfall	0.088	-0.338	0.5*	1				
% woodland species with >20% decrease in RR	-0.374	-0.065	-0.343	-0.376	1			
% woodland species with >20% increase in RR	0.224	0.113	0.486*	0.356	-0.925**	1		
% woodland species showing no change in RR	0.175	-0.437*	0.025	0.488*	-0.149	-0.056	1	
No. Woodland species	0.295	-0.934**	0.324	0.407	-0.112	-0.018	0.593**	1

*p≤0.05 **p<0.01

APPENDIX 5

Khalid al Dabbagh and companion atlasing in Chiltern National Park, Victoria.

Black Honeyeater nest, central Australia.

APPENDIX 5

Non-native vegetation such as this cereal crop, near Boorowa in NSW, favours birds such as Galahs and Crested Pigeons.

Birds responded both favourably and unfavourably to non-native vegetation cover. Here we have a mix of native trees with exotic understorey.

Brown Treecreepers showed regional variation, increasing in some bioregions, while decreasing in others.

Photo: P. Griffieon.

APPENDIX 5

The double-barred finch which depends on dense understorey vegetation was less likely to be recorded in the second atlas

Birds such as this eastern yellow robin have increased in reporting rate and were associated with rainfall and grazing by livestock.

Photo: P. Griffioen.

The blue-faced honeyeater showed greater reporting rates in bioregions that had increased rainfall.

Photo: P. Griffioen.

APPENDIX 5

Eileen Collins, Chris Tzaros and Andrew Silcocks atlasing in Chiltern National Park, Victoria.

Gang-gang Cockatoos showed a 44% decline in reporting rate and have been listed as Vulnerable in NSW.

Photo: P. Griffioen.

15% of all bird species require trees with hollows.

APPENDIX 5

The Australian Magpie showed no change in reporting rate between the two atlases.

Photo: P. Griffioen.

Favoured by the clearing and fragmentation of native woodland, Noisy Miners were recorded more frequently during the second atlas.

Photo: P. Griffioen.

Fruit-eaters such as this Rainbow Lorikeet have become more common, particularly along urban fringes.

Photo: P. Griffioen.

APPENDIX 5

The Australian pipit will nest in cereal crops.

Photo: J. Starks.

Finches such as this Red-browed Finch were recorded less frequently in the second atlas.

Photo: D. Fogels.

Natural regeneration of native woodland and the associated grassy understorey, provides habitat for ground-foraging birds.

A typical exotic pasture landscape near Armidale, NSW.

APPENDIX 5

How much native vegetation is enough?

Species such as this Superb Fairy-wren were more likely to be recorded in grazed landscapes.

Photo: P. Griffioen.

There is little habitat for woodland birds in intensive agricultural landscapes with exotic tree plantings.

APPENDIX 5

Birds responded both favourably and unfavourably to the extent of grazing by livestock.

Birds such as this Southern Whiteface can adapt change but their numbers continue to decline in many bioregions.

Photo: P. Griffioen.

Ground-foraging insectivores such as this Speckled Warbler are associated with leaf litter and native forbs (wildlifowers), a resource that is threatened by heavy grazing and fertilizer use.

Photo G. Chapman.

Open-country species such as this Stubble Quail will forage in cereal crops.

Photo: P. Griffioen.

APPENDIX 5

Ground-foraging insectivorous woodland birds, such as these Hooded Robins, were well represented among declining species.

Photo: G. Chapman.

The Varied Sittella, a typical woodland bird, was less likely to be recorded in the second atlas. However, other equally typical woodland birds had increased.

Photo: G. Chapman.

Bird species that had declined during the second atlas survey were associated with extensive native vegetation cover, which is often restricted to hills and slopes.

Photo: Sue McIntyre.